National Centre for Risk Analysis and Options Appraisal

River Geomorphology : A Practical Guide

Universities of Nottingham, Newcastle and Southampton

Guidance Note 18 October 1998

Publishing Organi

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This document contains information which will be useful to engineers, conservationists and managers interested in applying geomorphology to river management with the aim of protecting or enhancing the environment making a contribution towards achieving sustainable development.

Research Contractors
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GLOSSARY

The science of river geomorphology employs terms and concepts that will be unfamiliar to non-specialists untrained in geomorphology. To aid the reading and understanding of this document, this section presents a glossary of important words and terms.

Alluvial River
A river with a "self formed" channel. The size and shape (morphology) of the channel are the result of the entrainment, transport and deposition of sediment from the unconsolidated materials forming the bed and banks.

Bank Erosion
The process by which individual particles or aggregates of bank material are detached and removed by the river or some other erosive agent.

Bank Failure
The sudden collapse of a river bank due to inability of the soil to resist stresses imposed by the weight of the bank and/or pore water pressure within the bank.

Bank Retreat
The recession of a bankline into the floodplain due to either bank erosion acting alone, or together with bank failure through collapse followed by basal clean-out of failed debris.

Bankfull Flow
Flow which just fills the channel without over-topping the banks and inundating the floodplain. This flow is often taken to be the dominant or channel-forming discharge in a naturally stable, alluvial river. Catchment Baseline Study Broad, comprehensive study to provide an overview of the geomorphological 'state' of the rivers in a catchment, to establish their conservation value, define maintenance requirements and identify reaches with high potential for enhancement or retsoration.

Deposition
The laying-down of sediment due to the inability of the flow to continue to transport it as sediment load. Deposition usually occurs downstream of higher-energy, eroding reaches, along the channel margins or in slack water areas where stream energy is low.

Dominant Discharge
The flow rate which plays the most significant role in forming an alluvialchannel. This usually approximates to bankfull flow and often has a return period of one to two years (Annual Maximum Series) in a natural, stable channel.

Dynamic Equilibrium
The condition where the amounts of sediment entering and leaving a river reach are balanced so that there is no net change in bed level through time. A river in dynamic equilibrium may migrate across its floodplain through retreat of one bank which is matched by advance of the opposite bank.

Fluvial Audit
Initial geomorphological investigation used at the feasibility stage of project appraisal to ensure a geomorphologically-sustainable approach is taken. Relates sediment conditions in a problem or project reach to those prevailing in the catchment as a whole and establishes a semi-quantitative understanding of the reach sediment budget within a catchment context. The Fluvial Audit forms the basis for identification of historical and contemporary catchment factors which might contribute to current or future channel instability (termed 'potential destabilising phenomena' or PDP).

Fluvial Erosion
The process whereby particles making up the channel bed or banks are incorporated into the body of flowing water because the erosive shear stress applied by the flow.

Fluvial or River Geomorphology
The study of sediment sources, fluxes and sinks in the river system over short, medium and long timescales, and investigation of the resultant channel and floodplain morphology.

Fluvial System
The channel portion of the drainage network in a river basin including the flowing water, mobile sediment and the materials forming the bed and banks.

Geomorphological Approach
The application of river geomorphology to support channel design, operation and management strategies which are effective, cost-efficient, sustainable and avoid commiting future generations to inflexible solutions or expensive channel maintenance.

Geomorphological Conservation Value
Represents the susceptibility of an alluvial channel to being degraded by human activities (highly susceptible channels are the most 'natural': see Table 3.1) and is best defined by an experienced geomorphologist.

Geomorphological Dynamics Assessment
Detailed, quantitative geomorphological analysis of a problem reach applied during the design stage of a project, where more detailed appraisals are required. Deals particularly with linking morphological processes to associated channel changes (for example in establishing the degree to which bank erosion is a problem to channel stability).

Geomorphological Post-Project Appraisal
Study technique used to evaluate the the success of the project in terms of short-term objectives and long-term sustainability. Consists of two major elements: comparison of the actual installation of a project to the design plans (Compliance Audit) and monitoring of sediment, river dynamics, maintenance requirements and other activities (Performance Audit).

Management Solution
Solution of a morphological problem through allowing natural adjustment of the bed or bankline, reducing the threat posed by relocating facilities or activities away from problem locations or mitigating the problem by managing the cause of the morphological instability rather than the effects.

River or Stream Reconnaissance
A range of field techniques used to identify and inspect critical or project reaches during catchment baseline or fluvial audit surveys. The reconnaissance survey methodology employs standardised sheets to compile, record and store field evidence. Examples of reconnaissance sheets developed under a National R&D studies are included in the Appendices.

Sediment Load
Solid particles being transported by the river due to catchment erosion and/or fluvial entrainment from the bed and banks.

Sinuosity
Measure of the degree of meandering of a river. Ratio between channel length and straight line distance between two points on the river.

Stream Power
Quantitative measure of the ability of the flow to do work on the channel (and hence adjust its morphology) through sediment entrainment, transport and deposition. Usually expressed as stream power per unit bed area, which is the product of the unit weight of water, water discharge per unit width and channel slope.

Toe Scour
Fluvial erosion of the river bed adjacent to the bank that leads to an increased bank height and side slope angle. Toe scour may lead to bank failure and lateral shifting of the bankline if the bank soil is unable to support the stresses imposed by the weight of the bank.

SUMMARY

The purpose of this research publication is to provide practical guidance on the application of a geomorphological approach to river engineering, management and restoration. The primary user group are Environment Agency staff concerned with water management, flood defence, fisheries, recreation, navigation and conservation. However, the guidance available in this document might also be relevant to consultants, contracted to perform investigations which involve applied geomorphology or which must work in a way consistent with a geomorphological approach.

The guide should also be made accessible to other organisations and bodies concerned with river management and it may be of interest to individual landowners and developers. Throughout, information is presented in a modular fashion that allows users to access various elements without the need to read the entire document in detail.

River geomorphology provides a practical basis for the assessment, protection and enhancement of the physical environment in river channels. In this context, the Environment Agency can better achieve its objectives of protecting or enhancing the environment through adopting a geomorphological approach to river management. The geomorphological approach is also consistent with a holistic view of the environment and the application of geomorphologically-aligned design and managament can make a contribution toward achieving sustainable development and avoiding committing future generations to inflexible solutions or expensive channel maintenance.

To understand the advantages of the geomorphological approach, it is first necessary to grasp the principles of fluvial geomorphology. This presents a problem because the subject has until recently been regarded as academic and theoretical - taught in universities, but with limited practical relevance. As a result, few professionals have even a basic knowledge of river geomorphology. Hence, even in a practical guide, it is essential to outline the principles linking fluvial processes to the resulting channel forms that provide the basis for geomorphological observation, interpretation and analysis.

The advantages of the geomorphological approach stemming from these principles hinge on the capability: to classify channels according to their morphological features, stability, diversity and sensitivity to disturbance; to apply the knowledge so gained in predicting morphological responses to proposed projects; to assess the costs and benefits of alternative solutions to morphological problems, and: to select sustainable solutions that work with rather than against natural processes.

The application of geomorphology to river management has for some time been hampered by the lack of standardised and repeatable methods for geomorphological assessments. However, following applied research carried out through a series of Regional and National R&D Projects, there are now methods which may be recommended for use by Environment Agency personnel. The Guide provides a framework for performing geomorphological

studies in practice, moving from broad, catchment-wide overviews that set the context for project-related studies, to techniques for detailed investigation of process-form relationships at a specific reach.

Despite the lack of national guidance, the Agency has already made excellent use of applied geomorphology in a number of projects throughout England and Wales. Four case studies are used to demonstrate how geomorphology has already been applied successfully by the Environment Agency. The case studies present evidence not only on the environmental and aesthetic benefits of adopting a geomorphological approach, but also the cost savings over conventional solutions.

The Practical Guide concludes by presenting three Draft Outline Briefs developed to provide staff with guidance in either carrying out geomorphological studies themselves, or in contracting consultants. The Briefs are contained in stand-alone appendices that may be photocopied for future use by end-users, and are supported by background information on matching the expertise of the individuals performing the geomorphological study to the importance and complexity of the problem.

KEYWORDS

Conservation	Channel Maintenance	Engineering	Environment
Fisheries	Flood defence	Geomorphology	Navigation
Recreation	River management	River restoration	Sustainability

1. INTRODUCTION

1.1 Aims of the Guide

The aims of this guide to practical river geomorphology are to:

- establish the principles, contribution to the work of the Environment Agency and advantages of a geomorphological approach to river management;
- define the end-users of the geomorphological approach both within and outside the Environment Agency;
- set out the framework within which geomorphological studies should take place and provide practical guidance on the procedures involved in both planning and project-centred studies;
- present Case Studies to illustrate the procedures, outcomes, costs and benefits of adopting a geomorphological approach;
- provide end-users with draft Outline Briefs for the practical application of key geomorphological elements in river studies and management.

1.2 End-users: Practitioners, Clients and Customers

The end-user community for this guide is broad and encompasses:

- members of the staff of the Environment Agency in their capacities as practitioners, managers and intelligent clients;
- consultants, contracted by the Agency to perform investigations and analyses which involve applied geomorphology or which must work in a way consistent with the geomorphological approach to river management.

The guide should also be accessible to other organisations and bodies concerned with river management and may be of interest to individual landowners and developers. It is written in a modular fashion that allows users to access various elements without the need to read the entire document in detail. Chapter 2 sets geomorphology into its Environment Agency context, presents the principles that form the basis of geomorphological analysis and highlights the advantages of the geomorphological approach. Chapter 3 lays out the framework for applying geomorphological approaches in practice. Chapter 4 presents four case studies which demonstrate how geomorphology is already being applied successfully by the Environment Agency. Chapter 5 provides

practical background information on the Outline Briefs suitable for use by staff, clients and consultants during the formulation, tendering process and initiation stages of a project. The Outline Briefs themselves are contained in three appendices.

2. FLUVIAL GEOMORPHOLOGY IN THE ENVIRONMENT AGENCY

2.1 Objectives and Functions of the Agency

The objectives of the Environment Agency are defined under Section 4 of the Environment Act of 1995. A number of points in the statutory guidance to the Agency are relevant to the practical application of river geomorphology. The principal aims of the Agency include:

- "to protect or enhance the environment taken as a whole"
- "to make a contribution towards achieving sustainable development"

Geomorphological approaches have, in the past, been relatively neglected due to the emphasis placed on engineering solutions to problems of flood defence and land drainage, and to the higher profile of ecological issues in river management. While the application of river geomorphology in the Agency has increased markedly in recent years, progress has been unevenly distributed between Regions.

However, it is now widely recognised that geomorphological approaches to river management can assist the Agency in working towards its aims by:

- providing a practical basis for the assessment, protection and enhancement of the physical environment in river channels;
- enabling the Agency to take a holistic approach, by providing the appropriate tools for integrated geographical planning of the physical environment;
- supporting geomorphologically-aligned channel design and management strategies which are effective, cost-efficient, sustainable and avoid commiting future generations to inflexible solutions or expensive channel maintenance.

River geomorphology also has a number of practical applications relevant to the various Functions and Purposes of the Agency (DoE/MAFF/Welsh Office, 1995). Examples include, but are not limited to:

Agency Function	Application of river geomorphology
Water Management	Guidance on how to work with natural river processes rather than against them wherever possible.
Flood Defence	Accounting for and avoiding, where possible, disruption of natural river processes and wildlife habitats. Improving the efficiency of designs to meet multiple objectives. Advising on the best locations of structures (embankments etc.) to avoid erosion risks due to natural channel migration.
Fisheries	Designing restoration schemes to provide the morphological diversity needed to support a range of habitats, enhanced fisheries and increased species diversity.
Recreation	Improving river channel and riparian corridor aesthetics and attractiveness for a wide range of recreational purposes.
Navigation	Ensuring that navigation duties and maintenance programmes are performed with due regard to landscape, nature and conservation. Advising on sediment-related issues and problems.
Conservation	Providing the practical and technical guidance relevant to the Agency's duties to further conservation of natural beauty and physiographic features when exercising its powers, and to consider the effects of works on the landscape.

Geomorphological approaches are also consistent with the holistic, integrated treatment of the environment adopted by the Agency and they provide a vehicle for multi-functional analysis and planning in river management. Geomorphologists often provide the links between individuals from different disciplines that comprise project management boards overseeing major schemes.

Geomorphology is accustomed to dealing with a variety of spatial and time scales, making it valuable in developing new geographical planning tools and taking a long-term perspective on issues such as maintaining environmental capital and ensuring inter-generational equity.

2.2 Principles of Fluvial Geomorphology

2.2.1 Fluvial geomorphology - context and contributions

Fluvial geomorphology has been defined as, 'The study of sediment sources, fluxes and sinks in the river system over short, medium and long timescales and of the resultant channel and floodplain morphology' (Sear and Newson, 1994). Specialist disciplines other than geomorphology overlap with these interests, but it is important that in the procurement of services and establishment of clear lines of operation, the potential contributions of fluvial geomorphology are distinct from those of related disciplines such as civil engineering or freshwater ecology. The under-pinning contributions of fluvial geomorphology fall into three areas:

- assessment and classification of channels as an essential aid to the initial decisions on appropriate action;

- identification of the flow and sediment processes responsible for channel dynamics;

- linking processes of sediment erosion, transport and deposition to the resulting dimensions, features and stability of the channel.

In summary, the principles of the geomorphological approach are to investigate **causes** of river management problems related to the fluvial system (where ever they may be located), assess or design **remedies** at source and/or at the problem site(s) and attempt to reduce uncertainties about the **outcomes** of intervention from a knowledge of process time-scales. It is also essential to monitor and audit the morphological response of the channel to human interventions using the geomorphological approach.

2.2.2 What processes and patterns drive natural channel form?

Figure 2.1 shows how the flow of water and transport of sediment (driving variables) act within the context of valley, bed and bank materials and riparian vegetation (boundary characteristics) to produce the three-dimensional form of the channel. There is on-going research (via Environment Agency R&D initiatives) to derive a channel classification appropriate to the assessment and remediation of stability problems in the UK, although the additional dimension of time is, of course, critically important in practical management. Table 2.1 lists those parameters of the channel which adjust to changes in the flow regime, sediment transport or boundary characteristics. Hey (1982) has labelled these the 'degrees of freedom' which the channel to adjust may over time. The order in which adjustments occur will be specific to a particular channel type but the selected time-scale over which changes are considered has a bearing on the order in which they occur.

Table 2.1 Degrees of freedom of a river channel (from Hey, 1982)

Degrees of freedom (dependent variables) that respond to changes in:	Controlling variables
Velocity	Flow regime
Hydraulic radius (mean and max. depth)	Sediment load
Wetted perimeter (channel width)	Bed material size distribution
Slope	Bank material properties
Sinuosity	Riparian vegetation
Meander arc length	Valley slope

Figure 2.2 presents the critical variables in fluvial geomorphology as a framework for the explanations provided in the text below. The figure illustrates the complexity of the linkages between the flow regime, the sediment dynamics and landforms of the channel and floodplain. Emboldened captions in the boxes on the diagram are those treated in some detail here as principles of the geomorphological approach:

i) Sediment properties
Fluvial geomorphology involves collection of field data on sediment properties in order to understand the likelihood of fluvial erosion, transport or deposition under various conditions of flow; discharge data are normally available from hydrological sources, but there has been no systematic approach to the collection of data on fluvial sediments or their transport rate by agencies in the UK.

ii) Sediment supply
A fundamental principle of environmental management is to attempt to tackle problems at source; however, current approaches to river management seldom incorporate techniques for sediment source-area management and problems are usually tackled on-site, where they are apparent, rather than upstream, where they may originate.

iii) Channel sediment sources: bank and bed erosion
Where catchment sediment yields are small, river banks are likely to contribute most material to the fluvial system. Management of the banks (notably that involving the removal of natural vegetation) is intimately related to erosion rates, while gravel-bed rivers often show the highest rates of bank retreat because of the lack of cohesive strength in the bank materials. Studies of the surface armouring of gravel-bed rivers has led to the realisation that disturbance of the surface during, for example, dredging operations can destabilise entire reaches - in fact river engineering activity is one cause of observed major increases in sediment yield downstream since the 1960s.

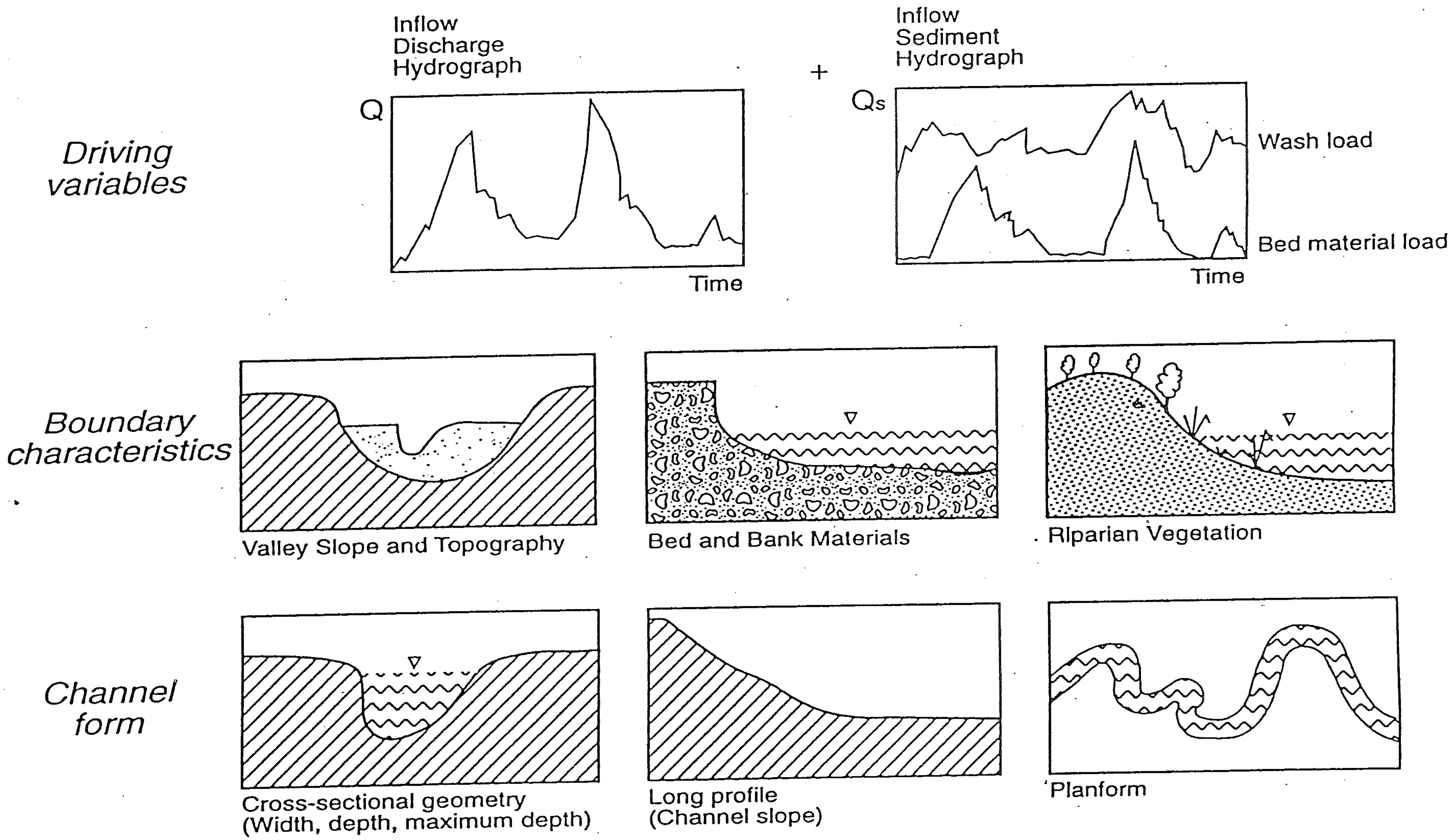

Figure 2.1 Driving variables and boundary conditions responsible for controlling three-dimensional channel form.

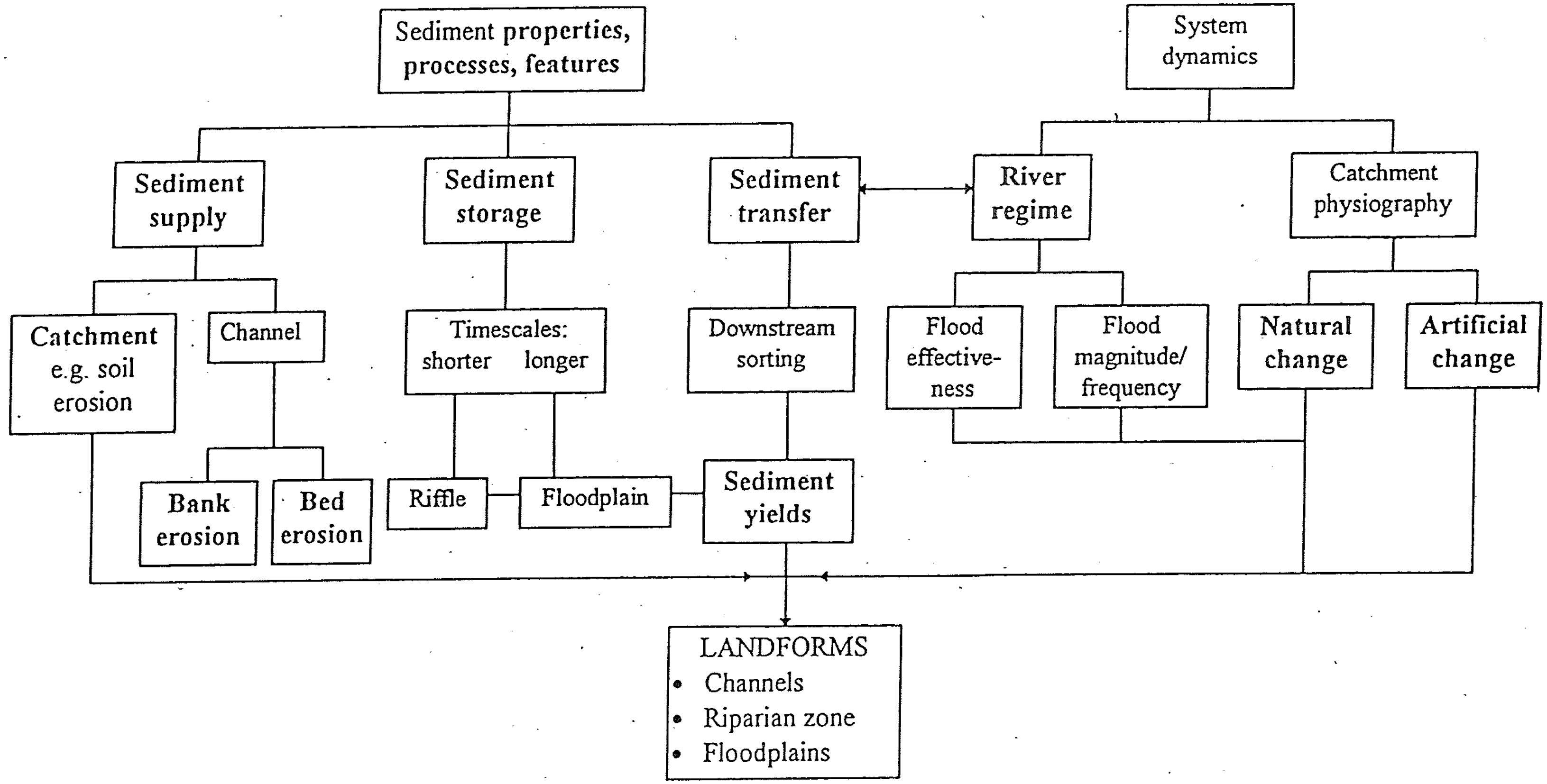

Figure 2.2 User guide to research information available to geomorphological applications (bold entries are referred to in the text).

iv) Sediment storage

Geomorphologists study the variety of landforms of the channel, riparian zone and floodplain in terms of the sediment transfer time-scales and storage durations involved in their creation. These sediment-related factors relate to the problems of, for example, maintaining channel flood capacity whilst still protecting the channel environment. The riffle is a short-term storage element and the point-bar is a more permanent feature in an eroding environment, whereas the shoals of sediment which accumulate in floods or in over-widened channels can be selectively redistributed without undue disturbance to the system.

v) Sediment transfer

Many geomorphologists have a research interest in sediment transport; however, use of the alternative term *sediment transfer* emphasizes that geomorphology treats the whole system in which transfer provides the link between sediment source and deposition areas. The use of physical models or flume studies to develop sediment transport formulae can only supply part of the answer to the larger problem of characterising sediment transfer in the fluvial system.

vi) Sediment yields

By developing and applying a variety of techniques of trapping, tracing and sourcing fluvial sediments, UK geomorphologists have assembled an impressive database on catchment sediment outputs; simple equations for the yields of both small and large sediments and catchment areas have been derived.

vii) Flood impacts: magnitude, frequency and effectiveness

High in-bank flows and floods accomplish most work in the sediment transfer system, but they are not equally effective in forming the channel morphology. The recent runoff history of a catchment is an important control on its contemporary sediment dynamics through the influence of channel changes and sediment supply from both the bed and banks.

viii) Natural and artificial change: time-scales

In the past, river management tended to follow project time-scales (for example, a time-scale related to Standards of Service for flood defence). The principle of sustainable development has helped, however, to shift the management focus towards longer-term solutions which may be flexible to changing environmental conditions. This requires an appreciation of reality of channel change over time. A historical element to geomorphological study provides useful, although often qualitative, information obtained from archival material and floodplain excavations. Models of longer-term stability, equilibrium and feedback are also very important to such considerations of sustainability and to control-at-source philosophies and policies.

2.3 Advantages of the Geomorphological Approach

The advantages of applying the principles of river geomorphology to channel management are that they allow practitioners, managers and policy makers to:

- determine the current morphological type (or classification) of the channel and establish whether this is appropriate to the catchment, landscape and local heritage;

- establish channel stability status and assess whether morphological forms and features are adjusted to prevailing flow processes, sediment dynamics and bank materials;

- characterise the degree of morphological diversity present and assess whether this is appropriate to the channel type and the range of habitats required to support the desired level biodiversity;

- identify situations where changes of channel morphology are liable to destroy valuable natural or man-made resources due to natural evolution, current instability or through being unduly sensitive to destabilisation by minor changes in flow regime, sediment supply or river management;

- consider viable alternatives to traditional forms of river management that work with rather than against natural processes when dealing with river stability problems: that is, geomorphology provides a useful tool in options appraisal;

- allow accurate assessment of the costs, benefits and sustainability of achieving desired engineering, morphological and biodiversity aims, particularly with regard to flood defence, fisheries, recreation, navigation and conservation functions of the Agency.

There are, necessarily, uncertainties associated with geomorphological interpretations and these lead to some risks in the application of geomorphology to river management, but knowledge and the capability of the science is improving all the time.

2.4 Further Reading

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3. PROCEDURES

3.1 Framework for Geomorphological Studies

River geomorphology has now contributed widely across a range of river channel management issues within the Agency. This has occurred through a combination of strategic NRA/Environment Agency research funding, application of geomorphology by practioners in some of the Regions, applied research undertaken at Universities and the geomorphological consultants. Involvement has been targeted in six areas, as shown in Figure 3.1 ('nested' components indicate areas that can be dependent on the results of previous analyses). These areas of involvement are not peculiar to geomorphology but have parallels with procedures carried out in Environmental Assessment and Engineering Project Management.

A number of broad areas of work that could benefit from a geomorphological approach have been identified. Planning studies, such as Catchment (or sub-catchment) Baseline Studies can be used to provide an overview of the geomorphological 'state' of the rivers and their conservation value. More focused, project-centred studies begin with a Fluvial Audit, the geomorphological equivalent of an 'initial environmental evaluation' used at the feasibility stage of project appraisal to ensure a geomorphologically-sustainable approach is taken. Where more detailed appraisals are required, especially in relation to morphological processes and associated channel changes (for example in establishing the degree to which bank erosion is a problem), several techniques are available to provide a Geomorphological Dynamics Assessment. This is a detailed, quantitative analysis of a specific, problem reach. These studies lead logically into Geomorphologically-Aligned Design Guidelines for sustainable approaches to maintenance schemes or capital works. Finally, the establishment of Geomorphological Post-Project Appraisals is critical as the basis for future improvements to river channel management. These methods are reviewed briefly in the following section.

Although there are, as yet, no recognised professional standards for geomorphological assessments, applied research carried out through a series of National Rivers Authority National R&D Projects mean that, for several of the procedures named above, there are now methods which may be recommended for use by Environment Agency personnel. Briefing documents have been developed to provide staff with guidance in carrying out the procedures or in contracting consultants. These are contained in the appendices to this document and should be photocopied for future use by end-users.

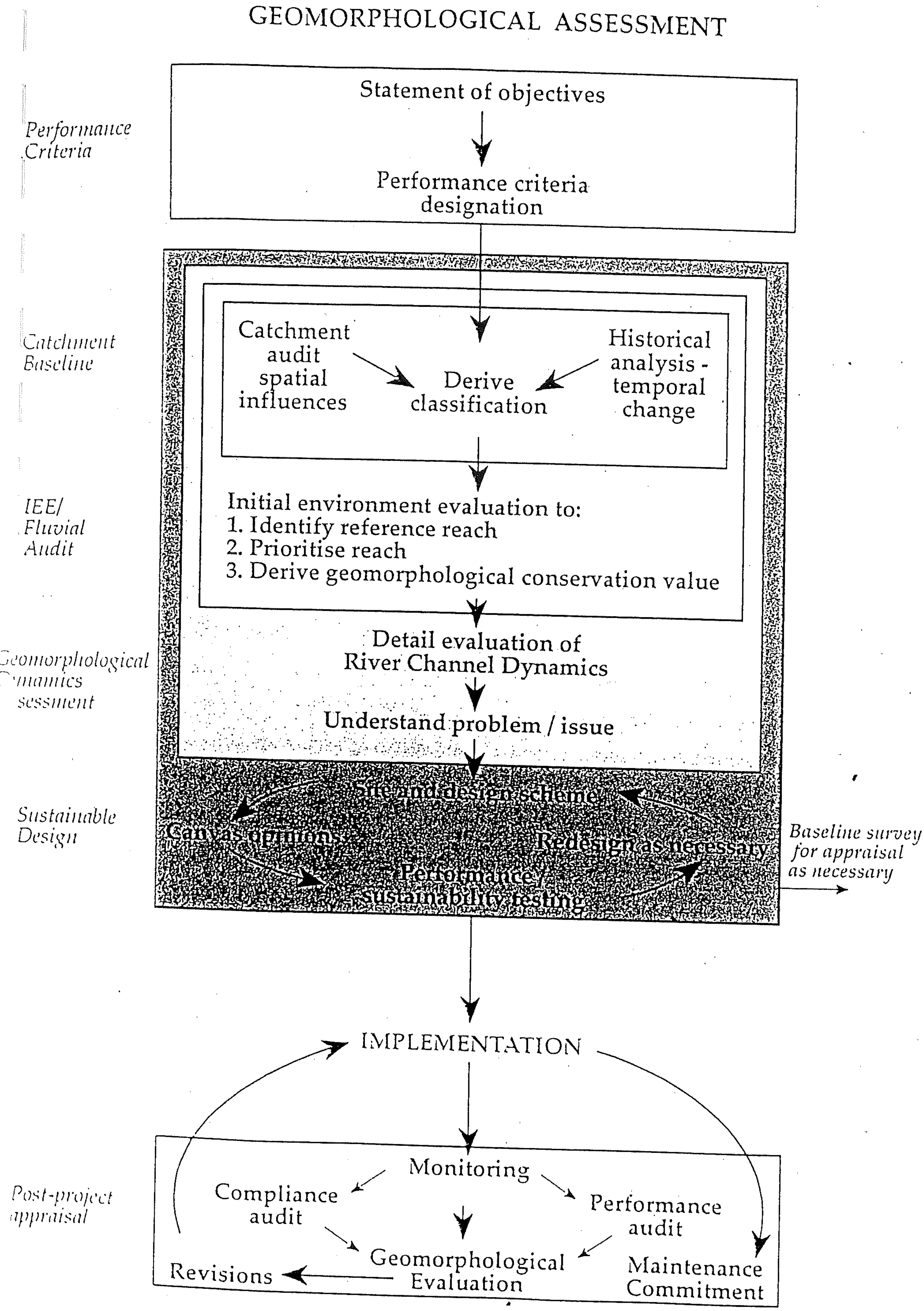


Figure 3.1 Framework for geomorphological assessment. The equivalent stages in an environmental assessment are shown for comparison.

3.2 Planning Studies

3.2.1 Catchment baseline study

The Catchment Baseline Survey provides a strategic overview of the geomorphological 'state' of the rivers and their geomorphological conservation value. This knowledge can be used to guide catchment planning priorities and it also enables staff to respond rapidly to requests for information about the geomorphological conservation value (and thus protection status) of channels liable to be affected by development proposals, changes in maintenance operations, or proposed capital works for flood defence or land drainage. A commitment to strategic baseline surveying will make geomorphological information available prior to and during project formulation and, thus, reduce the prevalence of reactive management. The baseline survey can be undertaken at one of two levels.

Firstly, a broad assessment of the geology, soils, topography, land-use and geomorphology of the catchment can be performed through a desk study using documented information supplemented by information obtained through consultation with relevant Environment Agency staff and a 1-2 day site visit to key locations within the catchment. The resultant summary (1 to 2 pages) of catchment characteristics and issues can then be used to provide input to LEAPs and, potentially, other regional or strategic planning studies (see Section A1, in Appendix A).

At the second, more detailed, level an assessment of the character of the channel within a catchment can be undertaken, with the data used to sub-divide the river network into channel lengths which have similar geomorphological properties (see Figure A2, in Appendix A). The detailed assessment methodology centres on a field survey to collect data about the present morphological condition of the river channels. This information is then combined with the results of the desk study to classify the reaches according to their 'geomorphological conservation value'. Geomorphological conservation value reflects the channel's susceptibility to being degraded by human activities (highly susceptible channels are the most 'natural', see Table 3.1) and is best defined by an experienced geomorphologist.

The information obtained from a detailed catchment baseline survey can also be used to gauge the degree to which channel reaches are stable, the extent and locations of modified channels and the potential for modified channels to 'recover' towards a natural state. As well as use for planning purposes, this information might be used as the basis for revising operational maintenance regimes to allow natural recovery or to determine the potential for river rehabilitation or restoration.

This type of Geomorphological Survey can be viewed as the geomorphological equivalent of a River Corridor Survey and should have similar costs, but it provides a cost-effective investment in terms of time and resource savings when information is required at short notice. It is estimated that a field surveyor will typically cover about 5km of channel per

day. Additional time should, however, be allowed for reaches where access is difficult, and this estimate does not include time for report writing.

The catchment baseline field survey uses a single sheet recording form (see Appendix A, Figure A1) together with representative photographs taken at each location. A record is made of the river's planform character and its gradient, flow and morphological characteristics. Geomorphologists carrying out the survey should also be able to record features which indicate on-going river channel changes resulting from natural processes or human activities. Riparian land uses and the extent and basic type of riparian vegetation are recorded, to assist in defining the conservation value. The survey results are suitable for storage in a Geographical Information System. For end-users, catchment-wide 'watercourse summaries' are prepared along with summary information sheets highlighting the locations of, for instance, rehabilitation priorities or unstable channels (see Table A1 in Appendix A).

Table 3.1 Summary of NRA (1990) scheme classifying river susceptibility to disturbance

Susceptibility to disturbance	Score	Description
High	8-10	Conforms most closely to natural, unaltered state and will often exhibit signs of free meandering and posses well-developed bedforms (point bars and pool-riffle sequences) and abundant bankside vegetation.
Moderate	5-7	Shows signs of previous alteration but still retains many natural features, or may be recovering towards conditions indicative of the higher category.
Low	2-4	Substantially modified by previous engineering works and likely to possess an artificial cross-section (e.g. trapezoidal) and will probably be deficient in bedforms and bankside vegetation.
Channelised	1	Awarded to reaches whose bed or banks have hard protection (e.g. concrete walls or sheet piling).
Culverted	0	Totally enclosed by hard protection.
Navigable	-	Classified separately due to their high degree of flow regulation and bankside protection, and their probable strategic need for maintenance dredging

3.3 Project-centred Studies

3.3.1 Fluvial audit

For reaches identified in the catchment baseline survey as experiencing sediment-related management problems, a Fluvial Audit should be performed to provide the basis for a geomorphological approach to finding a sustainable solution. The audit technique is designed to incorporate and build on the results of a catchment baseline survey but, where no catchment baseline survey has been performed, it can also stand alone.

The Fluvial Audit relates the sediment conditions in the problem reach to those prevailing in the catchment as a whole, paying close attention to sediment transport processes and the impacts of flood events and catchment land-use changes. Hence, the method is designed to establish a semi-quantitative understanding of the sediment budget for the river reach, within its catchment context. The audit provides useful information on sediment sources and pathways, geomorphological processes and the nature and causes of instability in the reach specified. It also produces a valuable baseline database against which to determine the impacts of any proposed capital works, including environmental enhancement, rehabilitation and restoration schemes, or changes to the maintenance regime.

In the case of proposed capital works, the Fluvial Audit comprises the first stage in selecting and planning a solution which is appropriate in terms of both flow regime and sediment dynamics. In cases of sediment-related maintenance issues (i.e. erosion or sedimentation), the technique enables the user to identify a managerial response that deals with the cause of the problem, rather than treating its symptoms.

The method uses a combination of archive data and field survey (see Figure 3.2). Archive data is used to estimate the location, timing and rates of channel change in the project reach and the catchment, to identify the character and timing of land-use changes and to identify changes in river management (for instance, to indicate when a river was straightened). Use is made of historical maps and aerial photographs in combination with records of flood defence, land drainage and maintenance operations held by the Environment Agency, Local Authority or other body. The field survey identifies the character of the reach and can, therefore, use the results from a catchment baseline survey, but should focus especially on evidence of erosion and deposition in the reach.

The assessment is used to provide three main outputs:

- time chart of catchment changes which may have impacted the fluvial geomorphology (Appendix B, Figure 1);
- a map indicating the catchment features important to the fluvial geomorphological character of the river channel (Appendix B, Figure B2);
- a detailed geomorphological map of the channel within and adjacent to the project/problem reach.

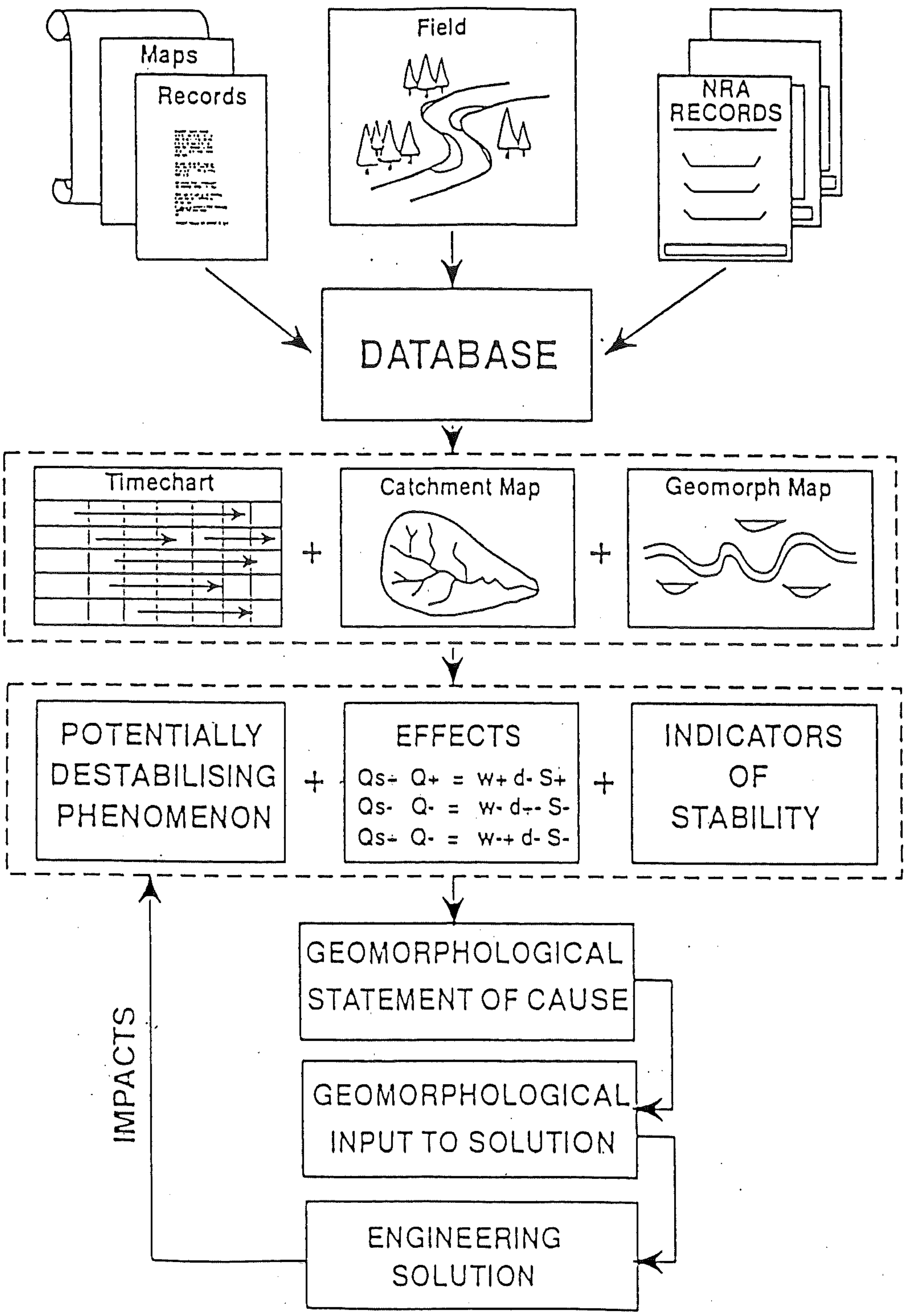


Figure 3.2 Data requirements for a fluvial audit.

River name: Blackwater		Reach: upstream of River Loddon confluence	
Input sources		*Input data*	
Stage discharge curve	✓*	Qsos actual	30·2*
Flow frequency distribution	✓*	Qsos target	23·8*
Sediment rating curve	✗	Qbankfull	16·4*
Catchment sediment yield	✗	Qoverbank	0·03
Channel slope	✓*	Q_{25}	31·9
Cross-section diagram	✓	Q_{50}	34·7
Bed material size distribution	✗	Average daily flow	2·9*
Bed vegetation description	✗	Mean annual flood	21·6

Bank vegetation

Select one of the following:

- Vegetation I — Grass bank, no trees/shrubs
- Vegetation II — 1–5 per cent trees/shrubs ✓
- Vegetation III — 5–50 per cent trees/shrubs
- Vegetation IV — >50 per cent trees/shrubs

Notes: *Ideally, all the data are required; however, the geomorphological assessment will function using the essential data marked with an asterisk if no other information is available

Qsos = Design discharge to provide the specified standard of service for flood defence
Actual = Standard of service currently provided
Target = Standard of service required

Comments on data

Data obtained from National Rivers Authority gauging station. Calculations of standard of service for flood defence, bankfull discharge and flows of given return periods by HR Wallingford. Bank vegetation category observed in field stream reconnaissance, July 1991

Dominant discharge calculated according to the method of Wolman and Miller (1960)

Dominant discharge	Qd=3·65 $m^3 s^{-1}$
Return period of dominant discharge	Td=<1·0 yr

Input data for quantitative analysis, River Blackwater, near the River Loddon

Table 3.5 Example of quantative measures for summarising river channel dynamics

Computational sheet for quantitative analysis, River Blackwater, near the River Loddon

Symbol	*Explanation*	*Measured value (from river survey)*	*Regime equation (Hey and Thorne 1986)*	*Calculated value (from regime equation)*	*Percentage difference*
w	width	12 m			
	vegetation I		4·33 $Qd^{0.5}$		
	vegetation II		3·33 $Qd^{0.5}$	6·36 m	+47
	vegetation III		2·73 $Qd^{0.5}$		
	vegetation IV		2·34 $Qd^{0.5}$		
d	mean depth	1 m	0·22 $Qd^{0.37}$ $D50^{-0.11}$	0·58 m	+42
dmax	maximum depth	1·4 m	0·20 $Qd^{0.36}$ $D50^{-0.56}$ $D84^{0.35}$	0·80 m	+43
Rw	riffle width	11.5 m	1.034 w	6·57 m	+43
Rd	riffle mean depth	0·9 m	0·9151 d	0·53 m	+41
Rd Max	riffle maximum depth	1·0 m	0·912 dmax	0·73 m	+27
F	form ratio	12	w/d	10·9	+9
A	cross-section	12 m^2	wd	3·69 m^2	+70
L	meander wavelength	90 m	12·34 w	79 m	+12
Z	meander arc length	50 m	6·31 w	40 m	+20
P	sinuosity	1·12	3·5 $F^{-0.27}$	1·84	−64
S	channel slope	0 001	0·087 $Qb^{-0.43}$ $D50^{-0.04}$ $D84^{0.84}$ $Qs^{0.10}$	not known	not known
ω	stream power	13 W m^{-2}	9810.Qd.S/w	5·6 W m^{-2}	+57
V	velocity	0·3 m s^{-1}	Qd/A	1 m s^{-1}	−233
Rv	riffle velocity	0·35 m s^{-1}	1·033 V	1·03 m s^{-1}	−194
	bankfull – dominant flow difference	16·4 $m^3 s^{-1}$	(Qbankfull-Qd)	3·65 $m^3 s^{-1}$	+350

Notes: Q=discharge; D=median-bed material size

Table 3.6 Example comparison of calculated hydraulic geometry parameters against observ channel parameters for the River Blackwater

These outputs are the basis for linking the solution of the management problem to its cause. Using an understanding of the sediment dynamics and geomorphological processes involved, and applying knowledge gained in previous geomorphological studies, a series of secondary products are derived including an identification of all the catchment factors which might contribute to channel instability, erosion or deposition (collectively termed 'potentially destabilising phenomena', PDPs), a summary of their likely impact on the channel and a collation of all reach indicators of channel stability/instability. The field survey is also used to approximate the amount and type of sediment storage and transport through the project reach. The primary and secondary products are combined to estimate the potential for change in the channel morphology which allows the geomorphologist to provide guidance in relation to the development proposal or maintenance problem.

3.3.2 Geomorphological dynamics assessment

A Geomorphological Dynamics Assessment forms the final and most intensive stage of a geomorphological study. The methodology requires a detailed, quantitative analysis of the channel in an individual problem or project reach to assess its morphology, geomorphological processes, process-form links and sensitivity to change. The field techniques employed are derived from research-level geomorphological studies and may include investigation of channel hydrology, fluvial hydraulics and the geotechnical properties of the river banks. Two of the most widely applied techniques are described below. The second of these stems from an NRA National R&D project into river bank erosion management (NRA, 1996).

Quantitative estimate of channel hydraulic geometry

The characteristic dimensions (width, mean depth, maximum depth, slope, planform pattern) and fluvial regime (mean velocity, stream power) of a channel define its hydraulic geometry. The hydraulic geometry observed for the existing channel may be compared to that predicted for a 'natural', stable channel using regime equations. Differences indicate the degree to which the channel form diverges from a stable condition either due engineering or instability. Several quantitative measures are used, including curves for flow-frequency, stage-discharge and sediment rating, along with measurements of cross-sectional dimensions, channel gradient and bankfull flow capacity (see Table 3.2).

Flow-frequency and sediment rating curves are used to perform a magnitude-frequency analysis of sediment transport and, thus, to establish the dominant discharge - that is the flow which transports the most sediment. As few rivers have a measured sediment rating curve, a sediment transport equation for bed material load may be used to synthesise a rating curve. 'Bankfull' discharge is estimated using the stage-discharge curve if the project reach is close to a gauging station or, if not, by using a catchment area-based adjustment or a hydrodynamic model. In a natural alluvial channels in dynamic equilibrium the bankfull and the dominant discharges should be similar, but this is rarely the case in British rivers due to the effects of past engineering.

Morphological channel parameters, including bed material size and bank properties, are obtained from field survey, large-scale maps and, in some cases, aerial photographs. Dominant discharge is used in appropriate geomorphological 'regime' equations to predict the hydraulic geometry expected for a stable, natural channel, including its cross-sectional geometry, planform pattern, longstream profile, fluvial hydraulics and the bankfull to dominant discharge ratio. Differences between the expected parameters and those observed in the field survey (expressed as percentages, see Table 3.3) indicate various types of morphological activity or the impacts of past engineering and management operations. The results are summarised and their implications are clearly set out for non-geomorphologists (Table 3.4).

Detailed reconnaissance survey for river bank management

Detailed reconnaissance surveys of individual reaches can supplement catchment baseline or fluvial audit surveys and are used to design appropriate and sustainable solutions to bank erosion issues. The reconnaissance survey methodology employs record sheets for compiling field evidence. Reconnaissance record sheets are typically used to store data analysis and for future reference. An example of reconnaissance sheets developed under an NRA National R&D study on bank erosion are included in Appendix C. These sheets are structured in Sections to record:

Section 1 — indicates the scope, purpose and logistics of the site visit;

Section 2 — contains an annotated sketch of the river planform and typical cross-sections through the project reach showing the locations of sediment sampling and photography points, significant flow patterns (especially where flow is directed at the bank), bank vegetation (which can strengthen or weaken the bank), bank structures and evidence for bank erosion and in-channel sedimentation.

Section 3 — records in detail the character of both banks, including the presence of structures and vegetation. This information, along with geotechnical properties of the bank and the condition of the bank toe, forms the basis for inferring bank erosion processes and determining bank stability.

Section 4 — identifies and characterises bank erosion and/or mass stability problems in the study reach, notes the balance between toe scour and siltation and includes space for field mapping of banklines and representative profiles.

Summary — draws together and summarises the observations, conclusions and recommended actions from the field reconnaissance.

To ensure consistency between surveyors, most sections are designed for 'tick-box' responses to a list of possible conditions and properties.

The reconnaissance survey contributes to river management by identifying the cause and probable rate of bank erosion through on-site identification of the erosion processes and failure mechanisms affecting bank stability. It is then necessary to relate these factors to the concept of 'basal endpoint control' whose central tenet is that in the medium to longterm bank erosion is controlled by the balance of sediment transported into and out the zone next to the bank toe. Where sediment transport upstream of the cross-section provides more sediment than that removed from the cross-section by erosion processes, sediment accumulation at the bank toe makes scouring of the lower bank leading to bank failure unlikely, and vice versa. Through understanding the geomorphological processes operating within the fluvial system it may also be possible to judge that even where erosion exists, it may be only a temporary or a very slow phenomenon which does not justify expenditure on intervention.

It is also important to understand that limited bank erosion is essential to ensure morphological diversity, regenerate riparian vegetation and drive in-channel carbon cycling which together create (and preserve) the habitats of conservation value in many rivers. Therefore, river managers may conclude that continued bank retreat should be allowed in some circumstances. Where erosion cannot be allowed, the reconnaissance survey should be linked to catchment-level analysis (catchment baseline and/or fluvial audit) to indicate the probable cause of erosion. In many UK rivers, it is human activities (including previous structural 'solutions' to bank erosion problems) which cause erosion, rather than geomorphological processes inherent to the fluvial system. Adopting this approach often leads to 'active' bank management solutions, such as:

- initiating continued monitoring where the significance or threat of the erosion problem is unclear;

- not treating the problem when treatment could prompt new problems in other (more sensitive) locations;

- relocating the threatened activity rather than attempting to preserve the bank alignment and position where this is economically more effective.

Where these approaches are not applicable, managing the cause of the problem is the next most appropriate solution; structural methods should be seen as a 'last resort' and should preferably involve "soft" engineering methods using some combination of vegetation along with flexible revetments rather than hard structural revetments. Overall, the bank management should seek to 'match the type, strength and length of bank protection work to the cause, severity and extent of the problem' and to bear in mind the need to balance conflicting goals in river management.
This 'geomorphological' approach to the management of river banks and the treatment of

bank erosion problems is incorporated into the latest Agency guidance document on these topics (Environment Agency, 1997)

3.3.3 Geomorphologically-aligned design guidelines

It is increasingly common to find geomorphological knowledge being applied in the design of channel management strategies. Initially, this involved the simple application of natural channel parameters to management designs, but the catchment geomorphological context is now recognised as critical to sustainable design solutions. Also, design solutions in high energy alluvial streams require more stringent procedures than for low energy streams where acute problems will develop slowly and can be tackled iteratively. Brief details are provided on two regional NRA initiatives to tackle geomorphological design issues.

Guidance for the installation of individual elements of geomorphological diversity

A series of eight guidance notes have been produced for the NRA Thames Region. Copies of these guidance notes may obtained by contacting Dr Andrew Brookes at the Agency's Centre for Risk Analysis and Options Appraisal in London. In summary, they cover procedures for carrying out the following river enhancements:

- design and location of pools and riffles - requiring mimicry of natural pool-riffle sequences in terms of spacing and location;
- installing or re-instating substrate - consideration should be given to should have appropriate grain size distribution, shape, and packing, and the capacity for natural replacement;
- planning channel profile changes - involving historical sources and direct surveys for quantitative information and the provision of asymmetric channel cross-sections matched to their sediment type;
- restoring river planforms - involving historical information, neighbouring 'reference' reaches and field data;
- installing bank protection - superseded by previous section;
- designing low flow widths - using reference reaches or hydraulic geometry equations along with reconnaissance surveys to indicate the potential for natural or prompted width 'recovery';
- designing multi-stage channels - critical issues include designing berm heights to reflect the inundation preferences for the desired habitat, keeping bank angles as low as possible and preserving or enhancing low-flow channel sinuosity;

- identifying evidence of channel change - planform change is evidenced using temporal sequences of large scale maps, aerial photographs, remotely sensed images with contemporary surveys, vertical changes are determined using repeat surveys, photogrammetric, dendrochronological or sedimentary records. River reconnaissance surveys are used where these sources are unavailable.

Restoration of flood alleviation schemes in steep gravel-bed rivers

Steep gravel-bed rivers in the UK often have a high conservation value, in part, due to their natural 'mobility' caused by high rates of bed load transport. As a result, they are extremely susceptible to degradation from flood alleviation schemes, while the performance of the schemes themselves may be impaired by channel 'recovery'. Therefore, flood alleviation schemes must be designed to have minimum impact on the river's natural stability and conservation values. Existing schemes should strive to maintain their flood defence capabilities but with significant enhancements to the river environment. The most appropriate solution, environmentally and economically, is to construct set back flood embankments but this is not always possible, particularly near urban areas. In all cases, the following strategic design guidelines are appropriate:

- establish the natural stability of the river in engineered and neighbouring reaches using geomorphological reconnaissance surveys;

- if necessary, stabilise the river in locations where instability is prevalent to prevent loss of flood capacity or need for excess maintenance;

- where set back flood banks are possible, liaise with hydraulic modellers to determine appropriate locations and levels of raised defences, and obtain water levels and velocities for a range of flows;

- for schemes which involve modifying the river, check the stability of the schemes by calculating the sediment transport continuity through the reach using Schoklitsch's method and by calculating the erosional resistance of the banks to surface erosion and to mass failure;

- where structural protection is necessary, use soft bank protection methods where possible and use instream structures to provide habitat diversit

3.3.4 Geomorphological post-project appraisal

Post project appraisals (PPAs) are an integral part of environmental assessment procedures and are essential to improve future operations. Specifically, Geomorphological PPAs compare the actual installation of the project to the design plans (Compliance Audit) and use systematic monitoring of sediment, river dynamics, maintenance requirements and other activities (Performance Audit) to evaluate the the success of the project in terms of

short-term objectives and long-term sustainability. GPPAs contribute to improved project design, facilitate impact management and aid the development of field practice. A particular problem with geomorphological PPAs is the time period required for a thorough evaluation. Because 'prompted' recovery (using geomorphological processes to achieve morphological improvements) is essentially weather-driven, the appraisal has to be performed with reference to the sequence of high, normal and low flows since implementation.

Clearly, a commitment to long-term monitoring is required. However, to offset short-term knowledge deficiencies, a rapid appraisal method to be invoked a year or two after implementation has been devised to provide two evaluations (Figure 3.3), first, whether the project meets short-term geomorphological objectives through compliance with the design brief and whether, in retrospect, particular design errors or unexpected benefits are now apparent and, second, whether the project appears sustainable in the medium to long term (a judgement requiring geomorphological experience).

Appraisals are initiated by collecting background documents to identify the key compliance and performance issues for a particular project. Field data are then collected relating to the key geomorphological variables, to check project compliance with the design and to collect preliminary information concerning scheme performance. Key variables will vary between projects but are likely to include the channel location (if realigned), its slope, cross-section and bed material compared to design documents. The preliminary evaluation of scheme performance requires an assessment of the river channel dynamics and sediment transport dynamics in the project reach, and the degree to which maintenance and other specific issues are met.

3.4 Further Reading

3.4.1 Catchment baseline surveys

Brookes, A. and Long, H.J. (1990) Stort Catchment Morphological Survey: Appraisal Report and Watercourse Summaries, Reading, NRA.

Brookes, A., Downs, P.W. and Long, H.J. (in press) A method for the geomorphological assessment of river channels at the catchment scale, Regulated Rivers: Research and Management.

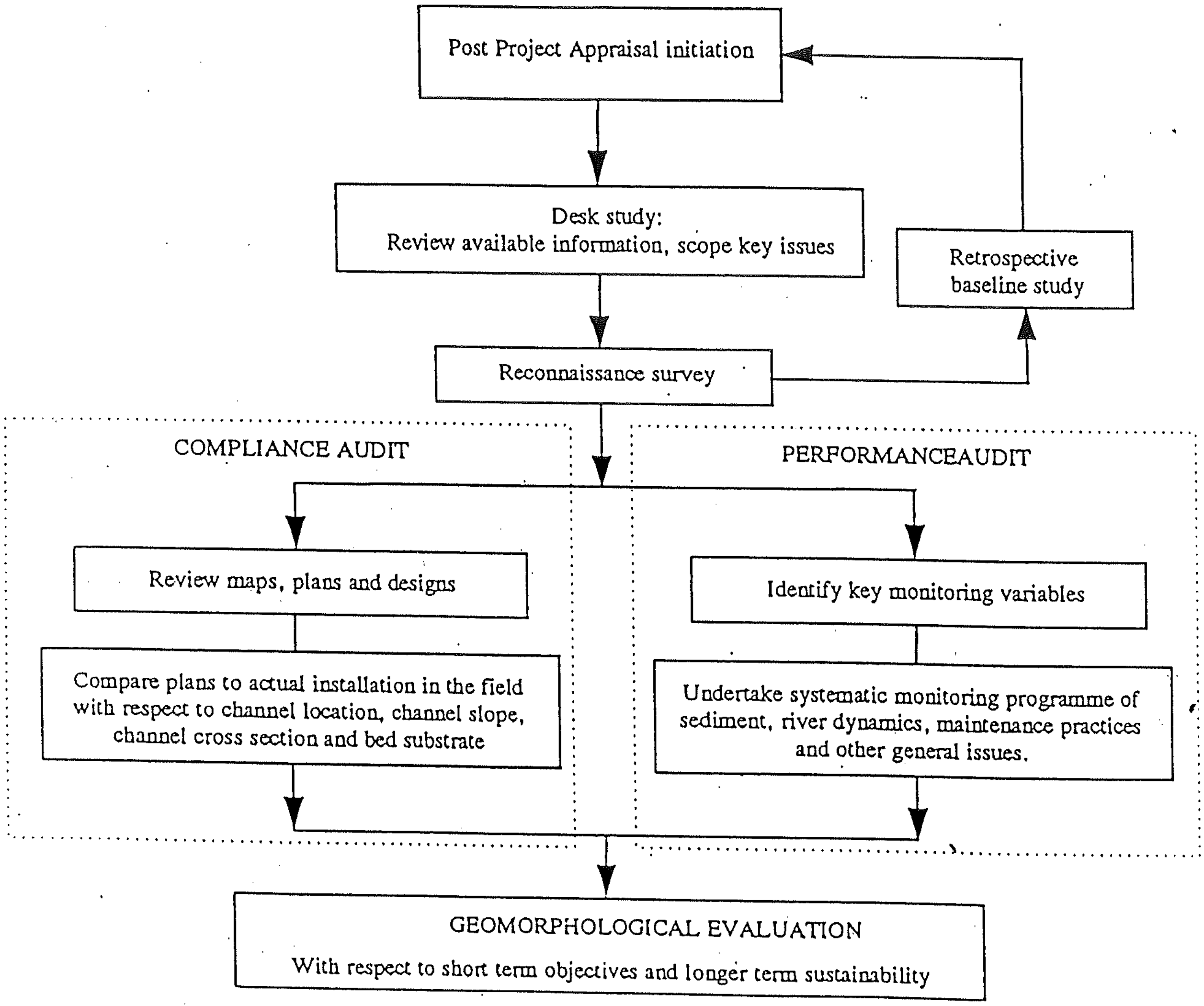


Figure 3.3 Geomorphological post-project appraisal methodology

3.4.2 Fluvial audit

National Rivers Authority (1994) Sediment and gravel transportation in rivers: A geomorphological approach to river maintenance. Policy and implementation recommendations, R & D Note 315, prepared by Sear, D. A. and Newson, M. D., Bristol, NRA, 28pp.

Sear, D.A, Newson, M.D. and Brookes, A. (1995) Sediment-related river maintenance: the role of fluvial geomorphology, Earth Surface Processes and Landforms, 20, 629-649.

3.4.3 Channel hydraulic geometry

Thorne C.R., Allen, R.G. and Simon, A. (1996) "Geomorphological stream reconnaissance for river analysis, engineering and management", Transactions of the Institute of British Geographers 21,

HR Wallingford (1992) Standards of service: reach specification methodology, report EX2652 to National Rivers Authority, Thames Region, Reading NRA.

3.4.4 Detailed reconnaissance surveys

Downs, P.W. and Thorne, C.R. (1996) "The utility and justification of river reconnaissance surveys", Transactions of the Institute of British Geographers, 21, 455-468.

National Rivers Authority (1996) A procedure for assessing river bank erosion problems and solutions, R&D Report 28, prepared for the NRA by Thorne, C.R., Reed, S. and Doornkamp, J.C., Bristol, National Rivers Authority.

3.4.5 Design guidelines

National Rivers Authority (1994) Development of Geomorphological Guidance Notes for use by Thames region NRA Regional/Area Fisheries and Conservation Staff, prepared for the NRA by GeoData Institute, Reading, National Rivers Authority.

National Rivers Authority (1993) Draft guidelines for the design and restoration of flood alleviation schemes, R&D Note 154, prepared for the NRA by Hey, R.D. and Heritage, G.L. Bristol, National Rivers Authority.

Environment Agency (1997) Waterway bank protection:a guide to erosion assessment and management, R&D Draft Technical Report W5/I635/3, prepared by Cranfield University, 261p.

3.4.6 Post-project appraisals

Downs, P.W., Skinner, K.S. and Brookes, A. (1997) Developing post-project appraisals for environmentally aligned channel management, IAHR XXVII Congress Water for a Changing Global Community, San Francisco.

National Rivers Authority (1996) 'Geomorphological post-project appraisal of the River Ash flood alleviation scheme', prepared for the NRA by Skinner, K.S. and Downs, P.W., Reading, National Rivers Authority.

4 CASE STUDIES OF RIVER GEOMORPHOLOGY IN THE ENVIRONMENT AGENCY

4.1 Introduction

River geomorphology has already been applied throughout the Agency to assist in the management of a range of projects (Figure 4.1). In most cases, geomorphological guidance produces two levels of solution;

1. short term assessment of the problem and solutions/designs;
2. longer-term appraisal of the role of intervention at a site.

To illustrate the varied application of river geomorphology, four case studies are presented. These were chosen because they cover a range of river types, have been through the project management process in most cases to implementation and for which financial information was available. Although representative of the broad areas of application it is stressed that the specific solutions, designs and costs are unique to the problem site presented. Individuals recognising similar problems should refer to Section 2.0 and decide what level of geomorphological involvement is required to reduce uncertainty and increase the cost effectiveness of any treatment.

For each case study there is a cost involved which is based on:

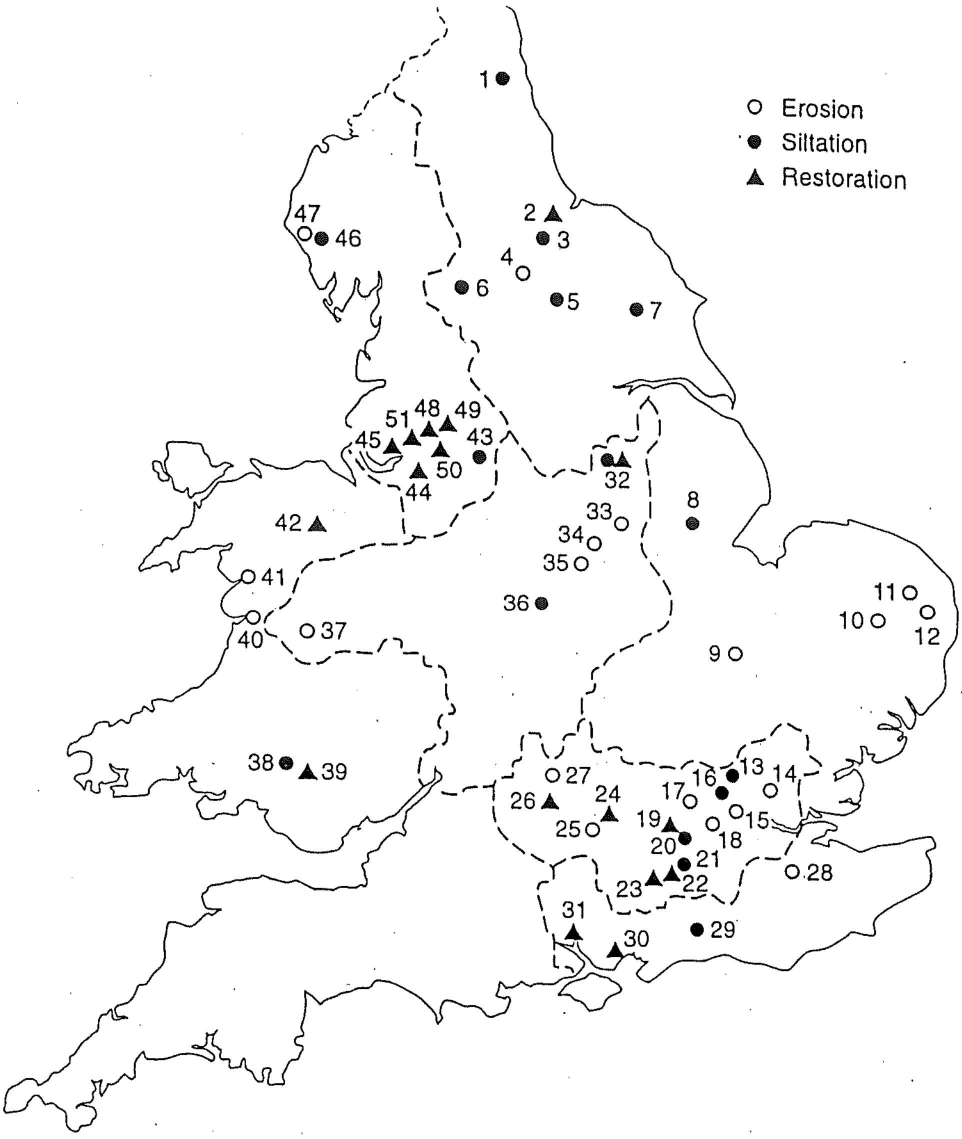
1. experience of the contractor (the greater the experience the more there can be confidence in the outcome);

2. type of project and, therefore, level of detail required;

3. scale of the project and, hence, the time required to collect and analyse information;

4. project or site-specific conditions, such as availability of existing data in-house or difficulty in accessing key field sites.

Further guidance considering these issues when setting up a geomorphological study is given in Section 5.



1. R. Wansbeck
2. R. Skerne
3. R. Swale
4. R. Ure
5. R. Skell
6. R. Wharfe
7. R. Derwent
8. R. Witham
9. Gt. Ouse
10. R. Yare
11. R. Ant
12. R. Bure
13. Bury Green Brook
14. R. Roding
15. Cobbins Brook
16. Mimmshall Brook
17. Radlett Brook
18. Salmons Brook
19. R. Thames
20. Chalvey Ditch
21. Parley Brook
22. Blackwater
23. Cove Brook
24. Bear Brook
25. R. Thames
26. R. Cole
27. R. Thames
28. R. Medway
29. R. Rother
30. Hermitage Stream
31. Monks Brook
32. R. Idle
33. R. Trent
34. R. Trent
35. R. Soar
36. R. Sence
37. A. Trannon
38. A. Tawe
39. A. Neath
40. A. Dovey
41. A. Wnion
42. R. Dee
43. Shelf Brook
44. R. Bollin
45. Whittle Brook
46. R. Liza
47. R. Ehen
48. R. Irk
49. R. Medlock
50. Padgate Brook
51. Prescot Brook

Figure 4.1 Location map showing sites where geomorphology has already been applied within the Environment Agency to assist in the management of a range of projects.

4.2 Case Study 1: Sediment Control using a Gravel Trap

Region	North West
River:	Shelf Brook, Steep upland gravel-cobble bed channel draining 14 km^2 of rough pasture/moorland.
Contacts:	S.Crowe (E.A.), Dr D.A.Sear (University of Southampton)
Problem:	Design and siting of gravel trap to reduce accumulation of sediment in an urban flood channel
Current Solution	Location of two traps upstream of urban channel within Peak District National Park
Cost:	£80,000 (1992 prices)
Geomorphological Input:	5-Day Fluvial Audit using standard Environment Agency assessment methodology at a cost of £1500 (see Appendix 1).
Cause:	Identified river cliffs and severe bank erosion during high magnitude events as main sources of gravel. Proposed location of traps identified as an area of natural sediment deposition. Potential for erosion of intervening channel between the proposed trap location and flood channel identified. Calculation of sediment yields suggested proposed trap capacity too high.
Solution:	Relocation of sediment trap outside NP boundary to upstream end of urban flood channel. Reduction in trap capacity and need for only one trap. Design to allow passage of some smaller gravels to feed limited morphological development in urban watercourse. Upstream site identified as natural sediment "trap" and retained as a natural geomorphological feature of flood protection value.
Cost	£40,000 (1992 prices) Geomorphological input <1% of total project cost.
Net saving	£40,000. Maintenance not required in 4 years. Preservation of natural physiological features upstream, and enhancement through controlled morphological development in FAS.
Comments	The geomorphological survey had a direct input into channel design and maintenance programming, leading to capital cost saving and reduced maintenance whilst preserving environmental features and flood protection. Clarification of the sediment transport system of this river provided E.A. staff with confidence in the proposed solution.

4.3 Case Study 2: Sediment Control in a Flood Defence Channel

Region	Thames
River:	Mimmshall Brook at Water End, gravel-bed river draining 52 km^2 catchment of mixed land-use including significant urban areas.
Contacts:	Brian Izzard (E.A.), Dr D.A.Sear (University of Southampton)
Problem:	Accumulation of gravels in flood channel
Current Solution	Annual desilt
Cost:	£10,000 pa (1992 prices)
Geomorphological Input:	5-Day Fluvial Audit using standard E.A. assessment at a cost of £1500 (see Appendix 1).
Cause:	Identified bank erosion in downcutting tributary 500m upstream as main source of gravels linked to increased efficiency of sediment transmission to flood channel through straightening of intervening channel.
Solution:	Hybrid solution recommended involving installation of check weirs in bed of tributary to reduce bank erosion and restoration of the sinuous channel course in the intervening reach to throttle sediment delivery.
Cost	£85,000 (1992 prices) Geomorphological input 1.8% of project cost.
Net saving	It is estimated that costs will be paid back in under 10 years through reduced maintenance requirement. Enhancement of the river environment upstream and a reduction in the disturbance of river habitat within flood channel
Comments	The geomorphological survey highlighted sources and pathways of both fine and coarse sediments that provided a catchment-based solution to the flood channel siltation and siltation of the Water End SSSI. Linking of cause and effect provided confidence in an off-site solution to recurrent siltation and river maintenance. Implementation is still pending at the time of writing.

4.4 Case Study 3: River Bank Erosion Management

Region	Southern
River:	Medway at Oak Weir, gravel-sand bed river draining 255 km^2 of mixed land-use.
Contact:	Brian Smith (Environment Agency)
Problem:	350m of river bank erosion downstream of radial gates.
Proposed Solution	Hard protection of bank face using layers of gabions
Cost:	£250, 000 (1990 prices)
Geomorphological Input:	1-Day Bank reconnaissance survey using Environment Agency standard assessment methodology at a cost of £300 (see Appendix 2). 1-Day design (£300). Design justification based on experience on smaller sites where faggoting had been shown to work.
Cause:	Scour of gravel layer below water level by hydraulic action caused by the operation of radial gates and boat wash. Undercutting of gravels lead to oversteepening of upper bank and collapse.
Solution:	Hybrid solution recommended, involving lower bank protection using gabion mattresses coupled with protection of the upper bank face using chestnut faggots.
Cost	£90,000 (1990 prices) Geomorphological input 0.7% of project cost.
Net saving	£159,700 resulting from geomorphological input.
Comments	Selection of a solution using soft elements was possible because river managers were ultimately more confident that they understood the causes, intensity and extent of the problem and had a commitment to providing the best solution in terms of efficacy, economy, engineering and environment.

4.5 Case Study 4: The River Restoration Project

Region	Northumbrian & Yorkshire and Thames
River:	Skerne at Darlington and River Cole at Coleshill.
Contacts:	River Restoration Project, Colin Platt (E.A.), Skerne -Prof M.D.Newson (University of Newcastle-upon-Tyne); Cole - Dr D.A.Sear (University of Southampton).
Problem:	Skerne: Restoration of 1 km of Urban Flood Channel. Cole: Restoration of 2 km of channelised river and floodplain.
Current Solution	Channelised land drainage channel of impoverished environmental quality (Cole). Channelised 2-stage urban flood channel of limited environmental quality.
Geomorphological Input:	Fluvial Audit using standard Environment Agency assessment methodology (see Appendix 1); Preliminary Design based on geomorphological principles. Costs: Skerne - £2,500; Cole - £6,000.
Solution	Skerne: Solution involved creation of meanders and reprofiling of banks whilst retaining flood capacity. Total project included hydraulic modelling of restoration features and channel, detailed project and environmental monitoring. Cole: Solution involved raising bed levels to increase flood frequency to restore wet riparian floodplain, and the creation of a meandering channel with pools, riffles and backwaters. Substrate reinstatement required in places. Total project included hydraulic modelling of restoration features and channel, detailed project and environmental monitoring.
Costs	Skerne: £190,000 (1996 prices) Geomorphological input 1.3% of project costs. Cole: £140,000 (1996 prices) Geomorphological input 1.4% of project cost.
Net saving	Intangible but clear that without geomorphological input, difficult to see how design would have been justified, given the complexity of the channel stability and morphological diversity needed to be assessed at this site. Maintenance costs at Cole site are likely to be reduced.
Comments	The geomorphological survey highlighted sources and pathways of both fine and coarse sediments that provided a catchment-based context for scheme design. Stability and morphology of current semi-natural channels in the catchment used to predict the dimensions and assess the feasibility of rehabilitation. On the Skerne, hydraulic modelling of restored design shown not to compromise current levels of flood protection.

4.6 Further Reading

Brookes, A. & Shields, D.G. (1996) 'River channel restoration', J.Wiley & Sons, Chichester, UK., 247pp

Brookes, A. (1987) 'Channelised Rivers: perspectives for ecological management', J.Wiley & Sons, Chichester, UK. 220pp

NRA (1996) 'A procedure for assessing river bank erosion problems & solutions', R&D Report 28, NRA Bristol, 48pp.

NRA (1994) 'Sediment and gravel transport in rivers: A procedure for incorporating geomorphology in river maintenance', Project Record 384, NRA Bristol, 225pp.

NRA(1991) 'Sediment & gravel transport in rivers including the use of gravel traps', Project Record, C5.02, NRA Bristol, 100pp.

Sear, D.A., Newson, M.D. & Brookes, A. (1995) 'Sediment related river maintenance: the role of fluvial geomorphology', Earth Surface Processes & Landforms, Vol 20, 629-647.

Sear, D.A., Darby, S., Thorne, C.R. & Brookes, A. (1994) 'Geomorphological approaches to river stabilisation and restoration: case study of the Mimmshall brook, Hertfordshire, UK.', Regulated Rivers, Vol 9, 205-223.

5. BACKGROUND TO THE APPENDICES

5.1 Introduction

These draft outline briefs have been designed to provide the basis for project managers and flood defence staff to procure the geomorphological services required to support a variety of projects. The briefs may be used as the starting point for the preparation of tender documents. Electronic versions will be made available through training courses provided by the Environment Agency. Each brief must be tailored to suit the specific project for which a geomorphological input is required and this is not a trivial task. In cases of uncertainty regarding the precise geomorphological requirements of the project, advice should be sought from a Regional Geomorphologist (if one is available) or from Dr Andrew Brookes at the National Centre for Risk Assessment and Options Appraisal.

5.2 Experience of Contractor

No formal industry accreditation currently exists for geomorphologists such as the chartered status available to Engineers and Landscape Architects. Geomorphology is only taught at undergraduate level in Departments of Geography, Geology or Environmental Science. Training is, however, now available within the Agency. Nevertheless, informal standards which can be used to QA prospective contractors do exist. In order of decreasing Quality Assurance these are:

- PhD in river geomorphology plus post-doctoral experience of working on applied river geomorphology projects (> 10, 5 or 2 years).

- Postgraduate training and higher degree in applied river geomorphology based on the analysis of contemporary fluvial processes and, if possible, relating this analysis to river management.

- Experience of working with the Environment Agency or equivalent sponsors in the area of river geomorphology and river management (> 10, 5 or 2 years).

- First degree from a Department of Geography, Environmental Science or Civil Engineering with a focus (dissertation research preferably) relating to river geomorphology.

Daily rates for geomorphologists fall generally within normal commercial ranges based on 1% of annual salary, incorporating overheads (e.g. £150 to £600 per person, per day).

It is important to recognise the different types of input that can be obtained from individuals with different degrees of specialisation and experience in river geomorphology. The role of geomorphological training within the Environment Agency is relevant in this context.

Levels of geomorphological specialisation, experience and capability are listed in Table 5.1.

5.3 Type of Project

The costs associated with each of the project types is largely a function of project complexity and levels of analysis and expertise required. Assuming a typical catchment and river, the order of decreasing study costs in person/days would be:

Catchment Baseline > Fluvial Audit > Post Project Appraisal > Bank Assessment

Actual costs will depend primarily on the scale of the catchment, river or problem reach. For example, the Assessment of 2km of eroding river bank requires fewer resources than a Fluvial Audit for a catchment of 500 square kilometres, but the time and effort might be almost equivalent if 50km of river bank were involved.

Table 5.1 Capability to perform geomorphological study in relation to specialisation and experience

Type of Contractor	Interpretation	Capabilities
Specialist and practitioner	Theoretical understanding plus experience in applying scientific principles to solve river management problems.	Able to provide science-based but practical solutions clearly and in terms understandable to non-specialists.
Specialist, non-practitioner	Academic theoretician, lacking experience in the application of geomorphology to the solution of real world problems.	Sound on principles of geomorphology, but will have a steep learning curve on practical issues of river management.
Trained non-specialist with field experience	Environment Agency river manager, engineer, ecologist, landscape architect etc., with training in geomorphology.	Can identify potential problems, solve straightforward cases and make reliable decisions as to whether more specialised advice is required.
Untrained non-specialist with field experience	Flood defence or drainage engineer, ecologist, landscape architect etc., with no training in geomorphology.	Able to recognise basic morphological features, with limited ability to interpret their significance or judge the need for specialised advice.

5.4 Project and Site-Specific Information

The costs of obtaining information specific to the project and site at hand vary widely, mostly as a function of the nature of that data, its availability in-house and difficulty in obtaining access to key locations in the field. For example, the availability of historical maps, hydrometric records and site plans from previous hydrographic and land surveys not only increases the information base for a geomorphological study but reduces staff and consultant time spent on data collection for the project. A significant cost in terms of time (though not necessarily in terms of costs) is involved where much of the geomorphological input is field-based or where data demands require liaison between groups with other specialist skills. Timescales and costs can vary widely around project norms as a result.

APPENDIX A - DRAFT OUTLINE BRIEF FOR CATCHMENT BASELINE STUDIES

Background

Catchment baseline surveys are used to provide a strategic overview of the geomorphological state of a river and its catchment, with particular emphasis on the conservation values of the various parts of the fluvial system. The methodology can also be used to put problem reaches into a catchment perspective, to address maintenance issues and to identify potential sites for enhancement or river restoration.
A commitment to catchment baseline surveys will increase the volume of geomorphological information available prior to and during project formulation, reduce reactive management and allow savings of cost and time when project-related geomorphological surveys are required at short notice. The methodology can be applied to a whole catchment or a single water course within a larger system.

The catchment baseline survey can be applied at one of two levels:

- Broad Catchment Survey of geology, soils, topography, land-use and geomorphology through a desk study, supplemented by consultation with Environment Agency staff and a 1-2 day site visit to key locations within the catchment. This level of survey can provide input to LEAPs and other strategic or regional studies;

- Detailed Catchment Survey of the geomorphological conservation value of a catchment, river system or water course on a reach-by-reach basis which uses field surveys to build on the results of an earlier broad assessment. This methodology provides the basis for staff to respond rapidly to requests for information about the geomorphological status and significance of reaches potentially affected by proposed capital works for flood defence or land drainage, changes in maintenance regime or catchment developments.

APPENDIX A1 - BROAD CATCHMENT BASELINE SURVEY

Aims

To provide a 1-2 page overview of the study area through broad assessment of the catchment and fluvial system. The report should identify and summarise key catchment characteristics, channel properties and management issues which can be used as inputs to LEAPs and as a guide to planning priorities at the strategic or regional level.

Methodology

i) Desk study of appropriate maps and accessible historical information and records relating to geology, soils, topography, land-use, geomorphology, ecological value and engineering interventions (for example: flood defence works; operational maintenance).

ii) Consultation with relevant Environment Agency staff (identified by the project manager and likely to include flood defence, operational maintenance, water quality, ecology, fisheries, conservation and geomorphology staff) to gather supplementary information and identify key issues such as erosion/sedimentation, maintenance problems and proposed/existing channel enhancement schemes.

iii) Site visit (1-2 days) to key locations within the study area to verify and update archive and institutional information. A geomorphological survey sheet (for example, Figure A1) should be completed and a photographic record made at each key location visited.

Outputs

A 1-2 page geomorphological overview of the study area with significant issues and problems identified clearly in the text and relevant maps, field survey sheets and photographs appended.

APPENDIX A2 - DETAILED CATCHMENT BASELINE STUDY

Aims

To provide a 5-10 page report characterising the geomorphological conservation value and susceptibility to degradation of a catchment, river system or watercourse on a reach-by-reach basis, identifying actual or potential problems and highlighting opportunities for improved river management.

Methodology

i) Desk study of appropriate maps and accessible historical information and records relating to geology, soils, topography, land-use, geomorphology, ecological value and engineering interventions (for example: flood defence works; operational maintenance).

ii) Consultation with relevant Environment Agency staff (identified by the project manager and likely to include flood defence, operational maintenance, water

quality, ecology, fisheries, conservation and geomorphology staff) to gather supplementary information and identify key issues such as erosion/sedimentation, maintenance problems and proposed/existing channel enhancement schemes.

iii) Field survey of the catchment and river using appropriate Geomorphological Baseline Survey sheets (for example, Figure A1) and photographs to record information and classify selected river reaches according to their 'geomorphological conservation value'. This reflects the channel's susceptibility to being degraded by human activities. Natural channels are the most highly susceptible to degradation.

iv) Preparation of a channel susceptibility map (for example, Figure A2) with channel reaches coded by colour or line type according to the scale presented in Table 3.1.

v) Identification of actual or potential problems and opportunities for improved river management in the catchment as a whole and within the sub-reaches, particularly with reference to the activities of the Environment Agency.

Output

A 5-10 page report detailing catchment characteristics and summarising issues, problems and opportunities relevant to the activities of the Environment Agency. A section presenting pragmatic suggestions for management or enhancement, and recommendations for further study (Fluvial Audit, Geomorphological Dynamics Assessment) may be included (for example, Table A1). Appendices containing geomorphological susceptibility maps, Baseline Survey sheets and photographs must be attached.

I	Date: *15 July 1990*	Surveyor: *H Long* Catchment: *River Stort*
	Tributary: *River Stort*	Reach Length: *200m* Reach Number: *73*
	National Grid Ref: *TL482130*	Orientation of Photographs: Looking North
	Description of Channel:	*Artificially overwide elongated reach*
II	Description of Catchment Context:	*Substantially agricultural catchment, with some major urban areas.* (Cv, Gz, F, U)
	Description of Floodplain:	*Wide, alluvial floodplain* (F,Cf, T)
	Description of Channel Planform:	*Previously straightened channel, low sinuosity* (HS, MS, LS, ST)
	Estimate of Channel Gradient:	*Low* (H, M, L)
III	Measured Low Flow Water Width:	*18.0m*
	Estimated Natural Low Flow Water Width:	*10.0m*
	Measured Low Flow Water Depth:	*1.5m*
	Estimated Low Flow Water Depth:	*0.3m*
	Estimated Bankfull Width:	*18.0m*
	Estimated Bankfull Depth:	*1.2m*
	Estimate of Bankfull Stream Power:	Low (H, M, L)
IV	River Bank Profiles:	*Steep, artificial* (S, B, Cl, A)
	River Bank Materials:	*Alluvium in both banks* (Cl, Si, Sa, G, Co, Bd, A) *% affected* by instability 0%
	River Bank Stability:	*No evidence of erosion or bank failure*
V	Description of Point Bars:	*poorly formed, loose silt, no vegetation* (Si, Sa, Co)
	Description of Pools:	*uniform bed, no natural pools* (Hd, Md, Ld, U)
	Description of Riffles:	*uniform bed, no natural riffles* (Hd, Md, Ld, U)
	Stability of Bed:	*considerable fine silt deposits* (Sb, Kn, Sd)
	Evidence of Bed-Load Transport:	*limited* (H, M, Lt)
VI	Impacts of Channel Management:	*channel is artificially wide and deep* (CV, FAS, ADS, LK, BP, RA)
	Potential Catchment Influences:	*silt deposits probably derived from disturbed catchment* (HV, HS, MV, MS, LV, LS)
	Recovery from Previous Impacts:	*limited, some siltation* (H, M, Lt)
VII	Presence of Channel Debris:	*limited organic debris*
	Bed and Bank Vegetation:	right bank % left bank %
	In channel	*90* *90*
	Banks	*100* *100*
	Riparian (trees)	*100* *25*
	Estimated likely Ecological Importance:	*moderate* (H, M, L)
VIII	Recommendations for Protection:	*low to moderate priority for protection* (H, M, L)
	Recommendations for Maintenance:	*possibly some silt removal* (Ds, Db, Vg, BP)
	Recommendations for Mitigation/ Enhancement:	*channel narrowing would have little impact* (Nd, Wr, Su, PR, Rp, Rm)

Figure A1 Example Geomorphological Baseline Survey Sheet for a detailed Catchment Baseline Survey, for the River Stort.

KEY TO SHEET CODING

II	Description of Catchment Context: Description of Floodplain: Description of Channel Planform: Estimate of Channel Gradient:	Cv = cultivated; Gz = grazed; F = forested; F = flat; Cf = confined; T = terraced; U = urbanised HS = high sinuosity; MS = moderate sinuosity; LS = low sinuosity; St = straightened H= high; M = moderate; L = low
III	Estimate of Bankfull Stream Power:	H = high; M = moderate; L = low
IV	River Bank Profiles: River Bank Materials:	S = steep; B = berms; Cl = cliff; A = artificial Cl = clay; Si = silt; Sa = sand; G = gravels; Co = cobbles, Bd = bedrock; A = artificial
V	Description of Point Bars: Description of Pools: Descritpion of Riffles: Stability of Bed: Evidence of Bed-Load Transport:	Si = silt; Sa = sand; Co = cobbles Hd = highly developed; Md = moderately developed; Ld = little development, U = under developed Hd = highly developed; Md = moderately developed; Ld = little development; U = under developed Sb = stable; Kn = knickpoint; Sd =deposits H = high; M = moderate; Lt = limited
VI	Impacts of Channel Management: Potential Catchment Influences:	CV = culverted; FAS = flood alleviation scheme; ADS = arterial drainage scheme; LK = lake; BP = bank protection; RA = realigned HV = high velocities; HS = high sediment loads; MV = moderate velocities; MS = moderate sediment loads; LV = low velocities; LS = low sediment loads
VII	Estimated likely Ecological Importance:	H = high; M = moderate; L = low
VIII	Recommendations for Protection: Recommendations for Maintenance: Recommendations for Mitigation/ Enhancements:	H = high; M = moderate; L = low Ds = desilting; Db = debris removal; Vg = vegetation management; BP = bank protection Na = narrowing; Wr = weirs/instream structures; Su = substrate instalment; PR = pool-riffle creation; Rp = reprofiling; Rm = remeandering

Figure A1 Continued

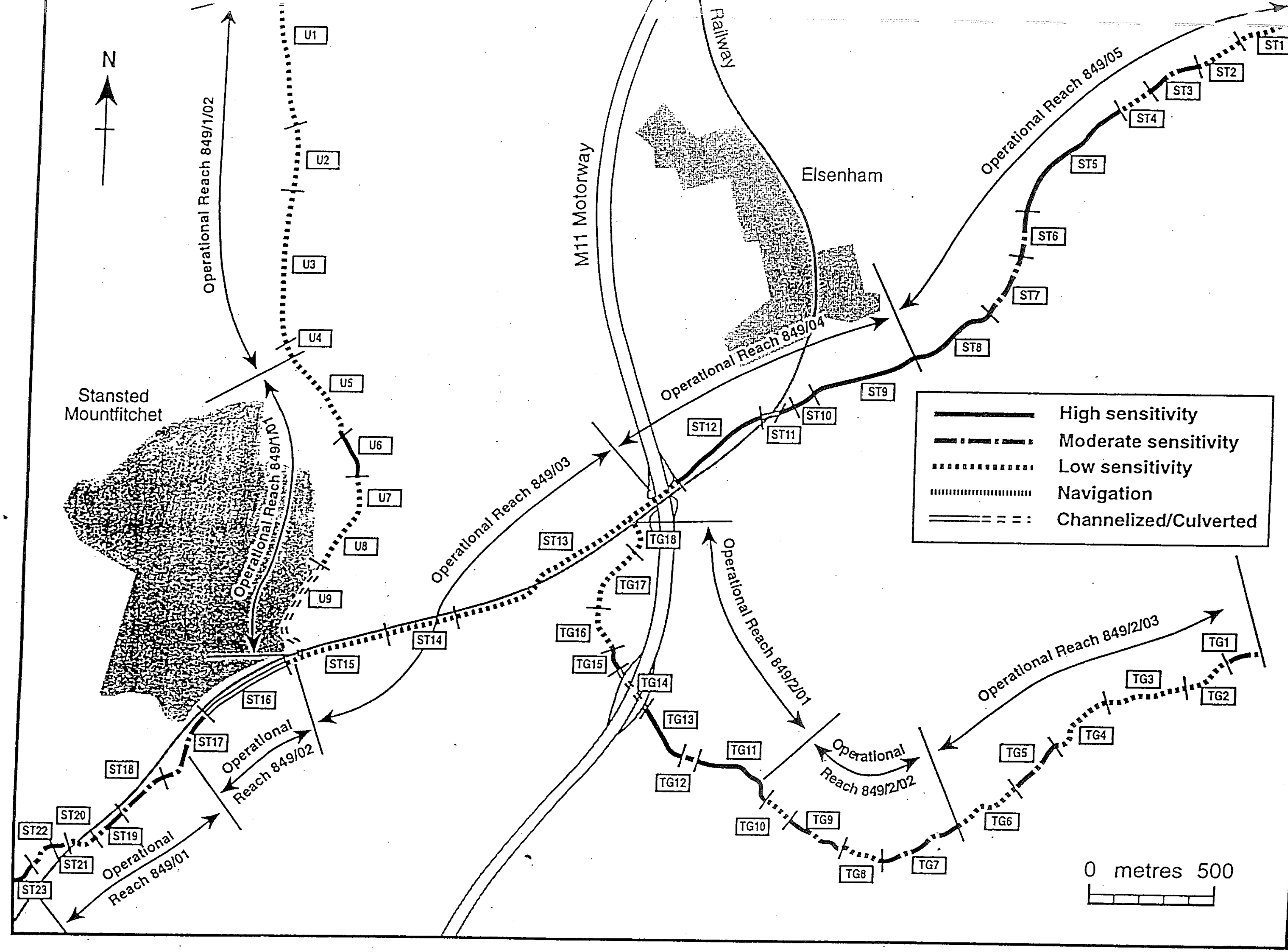


Figure A2 Reach-scale channel susceptibility map for the River Stort.

Table A1 Enhancement opportunities identified from a Catchment Baseline Study of the River Stort Catchment

Watercourse	Recommendations	Comments
Colville Hall	Scope for re-introduction of bends, gravels, pools and riffles, tree planting in all reaches.	Artificial agricultural stream. Full-scale enhancements may not be possible.
Fiddlers Brook	Re-introduction of gravels and formalisation of natural width.	Upstream reaches highly artificial. Channel narrowing and tree planting recommended.
Pole Hole Brook	Remaining natural reaches should be used as a guide for enhancement works. Seek expert advice. Tree planting and channel improvement in other reaches.	One reach lost to gravel extraction. Restoration should emulate natural reach upstream.
Tye Green Brook	Channel narrowing (deflectors, sills etc.) in overwide reaches.	Artificially wide but bends which have been retained assist natural recovery.
River Stort Flood Channel	Reduce channel size to recreate low-flow width. Use natural section for ideal width. Create berm to accommodate flood flows.	Flood channel through Bishops Stortford is overwide. Interest in enhancement.

Notes:
1. All enhancement works should take into account flood defence and operation requirements as a main concern.
2. This table identifies the type of reach that would benefit from enhancement works. Multi-discplinary advice should be sought to establish which reaches should be targeted for enhancement and which features are suitable.
3. Where the opportunity arises (e.g. as part of a development) enhancement works should be pursued.

APPENDIX B - BRIEF FOR FLUVIAL AUDIT

Background

The Fluvial Audit is used to relate the sediment conditions in a problem or project reach to those prevailing in the catchment as a whole. The technique establishes a semi-quantitative understanding of the sediment budget for the reach within its catchment context. This understanding forms the basis for identification of historical and contemporary catchment factors which might contribute to current or future channel instability (collectively termed 'potential destabilising phenomena' or PDPs), a summary of their likely impact on channel condition, a record of in-channel sediment storage and a collation of all reach-scale indicators of channel stability/instability.

Aims

To produce a substantial report building on the findings of a Catchment Baseline Study by presenting information on sediment sources, dynamics and storage in selected problem or project reaches within a catchment context, and determining the nature and causes of sediment-related problems or channel instability.

Methodology

i) Desk study to obtain overview of catchment geomorphology through review the findings of a previous Catchment Baseline Study, or by performing such a study if none exist.

ii) Select key reaches or sites for detailed field either on basis of existing geomorphological susceptibility map or initial field surveys using a Geomorphological Assessment sheet (see Appendix A1).

iii) Field surveys to assess sediment sources, dynamics and storage and identify the nature of sediment-related problems or channel instability. A Fluvial Audit Record Sheet, such as Figure B1, may be used to record data. Observations and measurements should include:

- cross-sectional data
- evidence of instability and its possible causes
- sedimentation patterns
- evidence of previous works and structures and degree of natural recovery
- effects of vegetation
- maintenance requirements
- protection and enhancement value

An assessment of the bank erosion case is conducted, to place the problem within the context of fluvial processes, morphological changes, human activities, river management and channel maintenance in the surrounding reach. Assessment is based on historical maps, archive information and hydrological/engineering records, together with river reconnaissance using a standardised reconnaissance record sheet (Figure C1).

Output

Report detailing the assessment process as described above. This will include:

I) assessment of the extent, severity, processes and mechanisms involved in the bank erosion problem;

ii) identification of its cause (both supported by reconnaissance survey findings and archive data);

iii) justification of either allowing the bankline to adjust to the problem or the need to intervene through either altered management or construction of structural protection;

iv) proposed management solution where the solution is matched to the problem and active bank management is preferred to structural approaches where feasible. In case of proposals for structural measures, soft engineering should be used in preference to hard solutions wherever possible.

BANK ASSESSMENT RECORD SHEET

SECTION 1 - SCOPE AND PURPOSE

Brief Statement of Bank Erosion Problem:-

Purpose of Bank Assessment:-

Logistics of Field Assessment Visit:-

RIVER NAME LOCATION DATE

PROJECT STUDY REACH From To

SHEET COMPLETED BY

RIVER STAGE TIME: START TIME: FINISH

General Notes and Comments on Bank Assessment Visit:-

Figure C1 Bank assessment record sheet for a detailed geomorphological dynamics assessment o bank erosion problem

SECTION 2 - CHANNEL SKETCH MAP

Map Symbols

Study reach limits	u/s limit d/s limit	North point		Cut bank		Photo point	
Cross-section	A——A'	flow direction		exposed island/bar		Sediment sampling point	
Bank profile		impinging flow		structure		Significant vegetation	

Representative Cross-section(s): Show locations on Sketch Map

A.

B.

C.

D.

Figure C1 Continued

SECTION 3 - BANK SURVEY

PART 1: BANK CHARACTERISTICS

Type
- Noncohesive ☐
- Cohesive ☐
- Composite ☐
- Layered ☐
- Even Layers ☐
- Thick+thin layers ☐
- Number of layers ___

Protection Status
- Unprotected ☐
- Hard protection ☐
- Soft protection ☐
- Mixed protection ☐

Bank Materials
- Silt/clay ☐
- Sand/silt/clay ☐
- Sand/silt ☐
- Sand ☐
- Sand/gravel ☐
- Gravel ☐
- Gravel/cobbles ☐
- Cobbles ☐
- Cobbles/boulders ☐
- Boulders/bedrock ☐

Layer Thickness
- Material 1 (m) ___
- Material 2 (m) ___
- Material 3 (m) ___
- Material 4 (m) ___

Ave. Bank Height
- Average height (m) ___

Ave. Bank Slope
- Average angle (o) ___

Bank Profile Shape
(see sketches in manual) ☐

Tension Cracks
- None ☐
- Occasional ☐
- Frequent ☐

Crack Depth
- Proportion of bank height ___

Distribution and Description of Bank Materials in Bank Profile

	Material Type 1	Material Type 2	Material Type 3	Material Type 4
Toe	☐	☐	☐	☐
Mid-Bank	☐	☐	☐	☐
Upper Bank	☐	☐	☐	☐
Whole Bank	☐	☐	☐	☐
D50 (mm)	___	___	___	___
sorting coefficient	___	___	___	___ (sorting coef.)

Notes and Comments on Bank Characteristics:-

PART 2: BANK STRUCTURES

Structure Type
- None ☐
- Revetment ☐
- Vertical wall ☐
- Sloping wall ☐
- Other (Specify) ☐

Materials
- Rock ☐
- Concrete ☐
- Brick ☐
- Timber ☐
- Steel ☐
- Other (Specify) ☐

Structure Data
- Date Constructed ___
- Length (m) ___
- Height (m) ___
- Side Slope (o) ___
- Orientation ___

Structure Condition
- Acceptable ☐
- Marginal ☐
- Unacceptable ☐

Problems Observed
- None ☐
- Flow Erosion of the structure ☐
- Flow scour next to the structure ☐
- Seepage failures in the structure ☐
- Slumping of the structure ☐

Notes and Comments on Bank Structures:-

PART 3: BANK-FACE VEGETATION

Vegetation
- None/fallow ☐
- Artificially cleared ☐
- Grass and flora ☐
- Reeds and sedges ☐
- Shrubs ☐
- Saplings ☐
- Trees ☐
- Orientation ___
- Angle of leaning (o) ___

Tree Types
- None ☐
- Deciduous ☐
- Coniferous ☐
- Mixed ☐
- Tree species (if known) ___

Density + Spacing
- None ☐
- Sparse/clumps ☐
- dense/clumps ☐
- Sparce/continuous ☐
- Dense/continuous ☐

Roots
- Normal ☐
- Exposed ☐
- Adventitious ☐

Location
- Whole bank ☐
- Upper bank ☐
- Mid-bank ☐
- Lower bank ☐

Diversity
- Mono-stand ☐
- Mixed stand ☐
- Climax-vegetation ☐

Health
- Healthy ☐
- Fair ☐
- Poor ☐
- Dead ☐

Age
- Imature ☐
- Mature ☐
- Old ☐

Height
- Short ☐
- Medium ☐
- Tall ☐
- Height (m) ___

Lateral Extent
- Wide belt ☐
- Narrow belt ☐
- Single row ☐

Notes and Comments:-

Figure C1 Continued

SECTION 4 - BANK PROBLEMS

PART 4: BANK EROSION

Erosion Location
- General
- Outside Meander
- Inside Meander
- Opposite a bar
- Behind a bar
- Opposite a structure
- Adjacent to structure
- Dstream of structure
- Ustream of structure
- Other (write in)

Present Status
- Intact
- Eroding:dormant
- Eroding:active
- Advancing:dormant
- Advancing:active

Rate of Retreat m/yr (if applicable and known)

Rate of Advance m/yr (if applicable and known)

Interpretative Observations

Severity of Erosion
- *Insignificant*
- *Mild*
- *Significant*
- *Serious*
- *Catastrophic*

Extent of Erosion
- *None*
- *Local*
- *General*
- *Reach Scale*
- *System Wide*

Processes
- *Parallel flow*
- *Impinging flow*
- *Piping*
- *Freeze/thaw*
- *Rilling + gullying*
- *Wind waves*
- *Boat wash*
- *Boat operations*
- *Other (write in)*

Distribution of Each Process on Bank

Process 1	*Process 2*	*Process 3*	*Process 4*
Toe (undercut)	*Toe (undercut)*	*Toe (undercut)*	*Toe (undercut)*
Lower bank	*Lower bank*	*Lower bank*	*Lower bank*
Upper bank	*Upper bank*	*Upper bank*	*Upper bank*
Whole bank	*Whole bank*	*Whole bank*	*Whole bank*

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments on Bank Erosion:-

PART 5: BANK GEOTECH FAILURES

Failure Location
- General
- Outside Meander
- Inside Meander
- Opposite a bar
- Behind a bar
- Opposite a structure
- Adjacent to structure
- Dstream of structure
- Ustream of structure
- Other (write in)

Present Status
- Stable
- Unreliable
- Unstable:dormant
- Unstable:active

Failure Scars+Blocks
- None
- Old
- Recent
- Fresh
- Contemporary

Interpretative Observations

Instability:Severity
- *Insignificant*
- *Mild*
- *Significant*
- *Serious*
- *Catastrophic*

Instability: Extent
- *None*
- *Local*
- *General*
- *Reach Scale*
- *System Wide*

Failure Mode
- *Soil/rockfall*
- *Shallow slide*
- *Rotational slip*
- *Slab-type block*
- *Cantilever failure*
- *Dry granular flow*
- *Wet earth flow*
- *Other (write in)*

Distribution of Each Mode on Bank

Mode 1	*Mode 2*	*Mode 3*	*Mode 4*
Toe	*Toe*	*Toe*	*Toe*
Lower bank	*Lower bank*	*Lower bank*	*Lower bank*
Upper bank	*Upper bank*	*Upper bank*	*Upper bank*
Whole bank	*Whole bank*	*Whole bank*	*Whole bank*

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments on Bank Geotech Failures:-

SECTION 5 - BANK TOE CONDITION

PART 6: BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris
- None
- Individual grains
- Aggregates+crumbs
- Root-bound clumps
- Small soil blocks
- Medium soil blocks
- Large soil blocks
- Cobbles/boulders
- Boulders

Vegetation
- None/fallow
- Artificially cleared
- Grass and flora
- Reeds and sedges
- Shrubs
- Saplings
- Trees

Age
- Immature
- Mature
- Old
- Age in Years

Tree species (if known)

Health
- Healthy
- Unhealthy
- Dead

Roots
- Normal
- Adventitious
- Exposed

Interpretative Observations

Toe Bank Profile
- *Planar*
- *Concave upward*
- *Convex upward*

Present Debris Storage
- *No bank debris*
- *Little bank debris*
- *Some bank debris*
- *Lots of bank debris*

Sediment Balance
- *Accumulating*
- *Steady State*
- *Undercutting*
- *Unknown*

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

Figure C1 Continued

Detailed Bank Map and Profile Sketches

Map and Profile Symbols

Bank Top Edge

Bank Toe

Water's Edge

Failed debris

Attached bar

Undercutting

Engineered Structure

Significant vegetation

Vegetation Limit

Bankline Map

Typical Bank Profiles (Show Locations on Bankline Map)

a

b

c

d

Figure C1 Continued

Bank Assessment Summary Sheet

Observed Condition of Bank including any Existing Protection

Location, Extent, and Severity of Erosion Threat

Significant Erosion Processes, Failure Mechanisms and Weakening Factors

Cause(s) of Problem

Suggested Action and Justification
(Allow Adjustment/Active Bank Management, Soft/Hybrid/Hard Structural Protection)

Figure C1 Continued